Planning Approaches for Water Resources Development in the Lower Mekong Basin

July 2011

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Acknowledgements

This report was funded by the United States Agency for International Development through a contract with AECOM International Development, which implements the Environmental Cooperation–Asia (ECO-Asia) project.

We thank Paul Violette, Peter King, and Ornsaran (Pomme) Manuamorn from ECO-Asia for their help with several aspects of the report preparation. We thank the Mekong River Commission (MRC) for their cooperation, provision of data, and detailed comments on earlier drafts. We also thank external reviewers for their helpful comments and suggestions on an earlier draft.

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List of Acronyms

AM	Adaptive Management
AusAID	Australian Agency for International Development
ADB	Asian Development Bank
BCA	Benefit-Cost Analysis
BDP	Basin Development Plan
BDP2	Basin Development Plan, Phase 2
CSP	Concentrating Solar Power
EGAT	Electricity Generating Authority of Thailand
ES	Ecosystem Services
FERC	Federal Energy Regulatory Commission
GDP	Gross Domestic Product
GPI	Genuine Progress Indicator
IWRM	Integrated Water Resource Management
IPP	Independent Power Producer
KBA	Key Biodiversity Areas
LMB	Lower Mekong Basin
MFU	Mae Fah Luang University
NREM	Center for Natural Resources and Environmental Management
MRC	Mekong River Commission
NPV	Net Present Value
OTEC	Ocean Thermal Energy Conservation
PAP	Project Affected People
PNPCA	Procedure for Notification, Prior Consultation, and Agreement
SEA	Strategic Environmental Assessment
SIDA	Swedish International Development Cooperation Agency
THPC	Theun Hinboun Power Company

Executive Summary

Governments in the Lower Mekong Basin (LMB) face decisions that involve trade-offs between, for example, the economic benefits from hydropower generation and potentially irreversible negative impacts on the ecosystems that provide livelihoods and food security to the rural poor. These decisions involve complex problems that are both poorly understood in scientific terms and subject to rapid, potentially catastrophic change over time. A comprehensive, whole systems approach that adequately addresses the risks and uncertainties involved is necessary, but this is a daunting challenge for researchers, decision makers, and managers. They must develop the capacity to plan, coordinate, and implement a program that improves sustainable societal well-being across national boundaries in the face of these uncertainties, which include impacts on native capture fisheries, biodiversity, wetlands and other biological resources, ecosystem services (i.e., the ecological characteristics, functions, or processes that directly or indirectly contribute to human well-being), and indigenous cultures and ways of life.

Significant effort has gone into analyzing these trade-offs and attempting to find the appropriate balance. A 1995 agreement mandated that the Mekong River Commission (MRC) develop a Basin Development Plan (BDP) with the objective of promoting the coordinated development and management of water and related resources at the basin level using the principles of Integrated Water Resources Management (IWRM). The first phase of the BDP Program (2001–2006) focused on establishing processes and a framework for participatory planning and improving the knowledge base and tools for water resources development. The second phase (2007–2010) of the BDP (BDP2) formulated and assessed basin-wide development scenarios, which facilitated the establishment of a shared understanding of development options in the LMB. Reflecting IWRM principles, the BDP2 planning scenarios are designed to cover not only hydropower but also other uses of the Mekong River as currently planned by all the LMB governments. The assessment of these scenarios under BDP2 was a dialogue tool in developing the IWRM-based Basin Development Strategy for the LMB, which was negotiated and agreed by all the member countries in January 2011. It is intended that this basin-wide, integrated planning will be a continuing, evolving process. Implementation of the Strategy and development of a subsequent Basin Action Plan will be core activities of the BDP 2011–2015 program.

An additional planning tool was the Strategic Environmental Assessment (SEA) to address the environmental issues surrounding the eleven planned mainstream dams. Commissioned by a different program within the MRC, the SEA provides detailed analysis on the potential impacts of the dams, thus complementing the BDP in providing a basis for discussion and negotiation of mutually beneficial levels of water resources development and their associated levels of transboundary environmental and social impacts. Full details of the BDP and SEA reports and the Strategy are available at http://www.mrcmekong.org/.

Both the BDP and SEA processes are part of the MRC inputs for LMB policy makers to reach an acceptable balance between development of the basin and maintenance of its ability to sustain livelihoods and environmental values. Recognizing the challenge and complexity of these processes in the LMB, our assessment is an effort to provide guidance on how these efforts can continue to evolve, improve, and be better integrated in future versions of the LMB plans. This assessment looks at:

1. how to deal with risk, uncertainty, and discounting the future;
2. a review of changes in fisheries that can result from planned developments in the basin, including hydropower development;
3. a review of methods to internalize the value of the ecosystem services currently being provided in the LMB and how these estimates might change under different development scenarios and different assumptions about key variables; and
4. some suggestions for how to better integrate and model all of these elements in an evolving planning process that incorporates a broader set of scenarios and a higher degree of stakeholder participation.

As one element of this assessment, a sensitivity analysis of the benefit-cost analysis (BCA) of certain BDP scenarios was undertaken. By changing some key assumptions in the BDP about discount rates, the value of lost capture fisheries, future aquaculture production in the LMB, and the value of lost ecosystem services from wetlands to reflect the full range of uncertainty, at the extremes, there could be a reversal of the net present value (NPV) estimates of the scenarios from positive to negative. This report considers the impact of applying some extreme, yet plausible, assumptions and estimates as a way to reflect the boundaries of this uncertainty. These estimates include: (1) changing from a 10 percent to a 1 percent discount rate for natural capital (but not aquaculture since it requires investment similar to other built capital); (2) assuming a $3/kg value of lost capture fisheries and aquaculture and reservoir fisheries gains (rather than $0.8/kg); (3) assuming that aquaculture may only replace 10 percent of lost capture fisheries (rather than most); and (4) using a value of ecosystem services from lost wetlands of $3,000/ha/yr (rather than $1,200/ha/yr). With these assumptions the overall NPV for the maximum development scenario would change from positive $33 billion to negative $274 billion.

While all BDP scenarios considered in the BCA had negative social and environmental outcomes, the possibility of a negative economic outcome should change the decision-making dynamics considerably. In addition, the distribution of benefits and costs in all scenarios was quite skewed. For example, after applying all the alternative assumptions, in nearly all scenarios Lao PDR had a positive NPV, while other LMB countries were often negative. Methods to compensate Lao PDR for foregone benefits from water resource development might be one way to achieve a better basin-wide outcome.

In addition, low probability but high impact events like earthquakes, mega-storms, and dam failures need further assessment as they could wipe out any potential gains.

Given this uncertainty, and the highly negative results that *could* occur (based on sensitivity analysis and experience in other countries), it is advisable to adopt a more precautionary approach and delay major decisions on infrastructure construction until a more thorough and comprehensive analysis can be performed, and institutions can be put in place to mitigate impacts. This is consistent with the recommendations of the IWRM-based Strategy, the SEA report, and the stated goals of the MRC.

As the Strategy has acknowledged, planning for major hydropower development in the LMB, whether on the mainstream or on the tributaries, needs to move beyond traditional linear

thinking to a more comprehensive, basin-wide, transboundary, participatory, "adaptive management" approach. It needs to recognize the breadth of uncertainties involved and develop policies and institutions that can take them more adequately into account. However, it also is recognized that the means by which to influence development decisions must be founded on transparent and mutually accepted analytical methodologies amongst the decision makers, an approach which the MRC has fully accepted.

Recommended next steps include:

1. A more comprehensive, integrated human and natural systems framework and adaptive management approach to LMB planning and development that deals with the entire watershed.
2. A more comprehensive analysis and treatment of risk and uncertainty. For example, dam developers could be required to post recoverable assurance bonds large enough to cover the worst case damages, as one method of shifting the burden of proof about impacts from the public to the developers.
3. A more thorough assessment of the value of direct and indirect ecosystem services. These services contribute extensively to sustainable human well-being in the region and need to be properly assessed and valued. Additional research along these lines would be highly beneficial. In addition, impacts of developments on indirect ecosystem services of the Mekong—both negative (e.g. loss of provisioning, regulating, and cultural services of the river) and positive (e.g. the multiplier effect of hydropower provision)—should be assessed in the next phase of BDP.
4. A broader set of scenarios that embody alternative models of development. In particular, models and assumptions that adopt the goal of sustainable human well-being more broadly conceived (rather than merely economic growth in the conventional sense) and employ alternative sources of energy should be part of the broader range of scenarios investigated.
5. Better treatment of the effects of infrastructure construction on local cultures and the poor. These effects should not only be noted, but should be prevented, mitigated, or, at minimum, compensated for before construction is approved.
6. Related to this, it appears that the benefits of hydropower construction, even in our worst-case scenario in the sensitivity analysis, are still positive for Lao PDR, while they are negative for all other countries. One approach that might be tried is to implement a form of "payment for ecosystem services" (PES) to Lao PDR (from the other countries in the LMB as well as elsewhere) that would be larger than the foregone benefits from dam construction. A similar approach has been proposed by Ecuador, in return for leaving major Amazonian oil reserves in the ground, and by Indonesia for leaving native forests intact, although these plans have yet to be implemented in either country.

The need for some of these steps was recognized in the BDP2 and they are consistent with, and build on, the recently released IWRM-based basin development strategy (MRC 2011). The Strategy states that there is "potential for some mainstream hydropower development, provided that uncertainties and risks are fully addressed and transboundary assessment and approval processes followed; although potential benefits are high, so are potential costs, including transboundary impacts" (MRC 2011, ii). Implementation of these steps in the next phase of BDP is strongly endorsed.

Introduction

Governments in the Lower Mekong Basin (LMB) face critical decisions about how to proceed with development of the mainstream Mekong River, as well as challenges about the cumulative impacts of developments on some critical tributaries, along with other water resource developments in the basin. These decisions may involve trade-offs between, for example, the economic benefits from hydropower generation and potentially irreversible negative impacts on the ecosystems that provide livelihoods and food security to the rural poor.

As an advisory body to LMB governments, the Mekong River Commission (MRC) has put significant effort into analyzing these trade-offs to inform decision makers in finding the appropriate balance in the utilization of Mekong water resources at the basin level. The MRC's position is set out in the Basin Development Strategy and the MRC Strategic Plan 2011–2015, which was approved in January 2011. Specifically, the MRC seeks to promote and coordinate sustainable management and development of the water and related resources of the Mekong Basin for the countries' mutual benefit and the people's well-being.

To achieve the above objective, the MRC was mandated by its 1995 agreement to develop a Basin Development Plan (BDP) to promote the coordinated development and management of water and related resources at the basin level using the principles of integrated water resources management (IWRM). The first phase of the BDP Program (2001–2006) focused on establishing processes and a framework for participatory planning and on improving the knowledge base and tools for water resources development. The second phase (2007–2010) of the BDP (BDP2) formulated and assessed basin-wide development scenarios, which facilitated the establishment of a shared understanding of development options in the LMB. The scenarios assessed within the BDP and discussed in this report were based on plans forwarded by each country, reflecting their request for an overall assessment of their current water resource development plans and ambitions at the basin scale. Reflecting planned multiple uses of the Mekong River, the BDP planning scenarios are designed to cover hydropower, irrigation, and flood plain management, based on IWRM principles. The assessment of these scenarios under BDP2 was a tool for dialogue in developing the IWRM-based Basin Development Strategy for the LMB, which was negotiated and agreed by all the member countries in January 2011. It is intended that this basin-wide, integrated planning will be a continuing, evolving process. Implementation of the Strategy and development of a subsequent Basin Action Plan will be core activities of the BDP program between 2011 and 2015.

In addition to the BDP, consultants were commissioned by a different program within the MRC Secretariat to conduct a strategic environmental assessment (SEA) to address the environmental issues surrounding the 11 planned mainstream hydropower projects. The SEA complemented the BDP2, which together provided a basis of joint understanding and discussion of development opportunities. This led to the formulation of the IWRM-based Basin Development Strategy (MRC 2011). Full details of the BDP and SEA reports and the Strategy are available at http://www.mrcmekong.org/. The MRC's formal position is set out in the Basin Development Strategy above and the MRC Strategic Plan 2011–2015.

Both the BDP and SEA processes are among key planning tools to provide inputs for LMB policy makers to reach an acceptable balance between development of the basin and maintenance of its ability to sustain livelihoods and environmental values. Recognizing the challenge and complexity of these processes in the LMB, the following assessment is an effort to provide additional analysis and guidance on how these planning approaches can continue to evolve, improve, and be better integrated in the future. It aims to contribute to the ongoing discussion on the economic, social, and environmental impacts of key policy decisions in the Mekong Basin. By applying new techniques to existing planning analyses, the report is also intended to provide key LMB stakeholders—the MRC Secretariat, member governments of the MRC, individual sectors within the governments, bilateral donors to the MRC (e.g., Swedish International Development Cooperation Agency (SIDA), Australian Agency for International Development (AusAID), and others), multilateral development banks (e.g., the Asian Development Bank (ADB) and the World Bank), nongovernmental organizations (NGOs), academics, and community groups—with additional information on potential sources of risks and uncertainties and to make recommendations on how to integrate and improve the assessment of LMB water resource management and development plans.

The first section of this report discusses general concepts on how to deal with risk, uncertainty, and discounting the future in analyzing the costs and benefits of decisions and investments. This is followed by a section which reviews potential changes in fisheries, a major ecosystem service of the Mekong River on which uncertain impacts from planned developments in the basin, including mainstream hydropower developments, could significantly influence the direction of costs and benefits of different development scenarios. Then the report provides a review of methods to internalize the value of the ecosystem services currently being provided in the LMB, using the examples of capture fisheries and wetlands, and considers how these estimates might change under different development scenarios and different assumptions about key variables. Based on these analyses, the report concludes with some suggestions for how to better integrate and model all of these elements of risks and uncertainties in an evolving planning process that incorporates a broader set of scenarios and a higher degree of stakeholder participation. Two appendices cover additional investigations into alternative energy developments and the likely social impacts of possible developments in the basin, as these considerations may be needed in future scenario development.

1. Risk, Uncertainty, and Intergenerational Issues

1.1. Background

Dealing with risk and uncertainty are key issues in any decision-making process. In making decisions about major infrastructure investments that affect millions of people for many years, these issues are especially important. In the Mekong, several plans put forwarded by LMB governments raise a major challenge in how risks and uncertainties are factored in at the planning stage. For example, decisions about building hydropower projects on the Mekong River mainstream have to take into account a huge range of risks and uncertainties, including, but not limited to: climate change, the impacts of earthquakes, the shift to dryland rice, impacts on capture fisheries including the complex effects of trophic cascades, the ability of aquaculture to replace lost capture fisheries, the impacts of biodiversity loss, the impacts of wetland and

forest loss, alternatives to dams as a source of electricity, and the distribution of benefits and costs among current stakeholders and among generations. In assessing current development scenarios, the BDP2 incorporated some of these uncertainties, but more comprehensive treatment of these issues could be done in the future. This section discusses some general concepts and types of risk and uncertainty and options for dealing with them in future analyses. In subsequent sections, some of these methods are applied retrospectively to the BDP2 analysis as a case study to demonstrate how they could be employed in the future.

It is first necessary to define some terms and differentiate between *risk* (which is an event with a *known* probability, sometimes referred to as statistical uncertainty) and *true uncertainty* (which is an event with an *unknown* probability, sometimes referred to as indeterminacy). One can think of a continuum of uncertainty ranging from zero for certain information, to intermediate levels for information with statistical uncertainty and known probabilities (risk), to high levels for information with true uncertainty or indeterminacy. Risk assessment has become the central guiding principle at many management agencies, but true uncertainty has yet to be adequately incorporated.

Science treats uncertainty as a given, a characteristic of all information that must be honestly acknowledged and communicated. Over the years, scientists have developed increasingly sophisticated methods to measure and communicate uncertainty arising from various causes. It is important to note that the progress of science has, in general, uncovered *more* uncertainty rather than leading to the absolute precision that the lay public often mistakenly associates with "scientific" results. The scientific method can only set boundaries on the limits of our knowledge. It can define the edges of the envelope of what is known, but often this envelope is very large and the shape of its interior can be a complete mystery. Science can tell us the range of uncertainty about global warming and toxic chemicals, and maybe *something* about the relative probabilities of different outcomes, but in most important cases it cannot tell us which of the possible outcomes will occur with any degree of accuracy.

Most decision-making processes, on the other hand, abhor uncertainty and gravitate to the edges of the scientific envelope. The reasons for this are clear. The goal is making unambiguous, defensible decisions. These are much easier if they are stated in clear, black and white, absolutely certain terms. Science defines the envelope while the decision process gravitates to its edges—generally the edge that best advances the decision-maker's own agenda. However, to make good decisions we need to deal with the whole envelope and all its implications.

1.2. Sources and Methods to Address Risk and Uncertainty

There are three principle sources of uncertainty in scientific analysis: parameter uncertainty, model uncertainty, and data quality. Gaps in knowledge or understanding can arise from any or all of these sources. These three sources are described below along with methods suited to addressing each.

1.2.1. Parameter Uncertainty

Parameter uncertainty refers to the uncertainty associated with model parameters and is also known as "within model" uncertainty. The usual way to communicate this uncertainty is

through statistics and sensitivity analysis of various kinds. The BDP2 report employed limited sensitivity analysis around some of the model parameters, but this could be done in a much more elaborate and systematic way. Simply stating a range of results based on a range of parameter settings is the simplest approach. For complex models a "Monte Carlo" approach is sometimes employed where parameter setting combinations are chosen at random from a preselected range and the model is rerun a large number of times to get a more complete picture of the full envelope of possible results (Fishman 1996). In subsequent sections we broaden the sensitivity analysis of BDP2 to express the range of results that could be obtained when certain important parameters (e.g., the value of lost capture fisheries, the value of lost wetlands, and discount rates) are varied over a larger range. These are discussed below.

1.2.2. Model Uncertainty

Model uncertainty refers to the uncertainty associated with the choice of model or with underlying assumptions. This is also known as "between model" uncertainty. The usual way to communicate this uncertainty is to display the results of alternative models or sets of assumptions. For example, the global climate change community supports the development of multiple global climate models, and a rigorous inter-comparison of model results has helped to communicate between model uncertainty. In the case of the BDP2, these assumptions have to do with a broad range of assumptions, including alternative models of what is meant by "development" (Costanza 2008). The conventional model of development emphasizes economic growth and does not worry much about the distribution of the benefits of that growth. An alternative model emphasizes quality of life and sustainable well-being more broadly defined and worries more about the influence of the distribution of benefits on this well-being and the contribution of nonmarket services like those from natural and social capital. One way to express this uncertainty is by using a broad set of future scenarios that embody this range of models. The BDP2 used scenario analysis, but only a limited range of scenarios that were variations around a single model, as BDP scenarios were created by combining current plans of LMB governments at different points in the future (2015, 2030, 2060), rather than the common scenario process of creating a full envelope of possible development alternatives. (The BDP scenarios are described in a later section). Hence, BDP2 was more a parameter sensitivity analysis as discussed above than a model uncertainty analysis.

1.2.3. Data Quality

Finally, there is uncertainty associated with the quality of the data going into the models and analysis. The famous saying, "garbage in–garbage out," captures this situation. But the methods to adequately communicate this source of uncertainty have not been adequately worked out or accepted. Data quality is often either ignored completely or oversimplified into "good" versus "bad" data, although the lack of good quality data on some issues is readily acknowledged in the Mekong Basin. There are emerging methods to deal with data quality (Costanza 2007), but in general this leads to a more precautionary approach to decision making and shifting the burden of proof from the public to the parties that stand to gain from the decision. For example, requiring assurance bonds to be posted by dam developers to cover the worst case potential damages would shift the burden of proof from the public to the developers and better incorporate the full costs of the dams (Costanza and Perrings 1990).

1.3. Discounting and Intergenerational Issues

Discounting of the flow of services from natural assets like capture fisheries or wetlands is somewhat controversial (Azar and Sterner 1996). The simplest case involves assuming a constant flow of services into the indefinite future and a constant discount rate. Under these special conditions, the NPV of the asset is the value of the annual flow divided by the assumed discount rate.

The discount rate choice is a matter of some debate. In previous work, Costanza et al. (1989) displayed results using a range of discount rates and showed that a major source of uncertainty in the analysis is the choice of discount rate. But beyond this, there is some debate over whether one should use a zero discount rate or whether one should even assume a constant discount rate over time. A constant rate assumes exponential discounting, but decreasing, logistic, intergenerational, and other forms of discounting have also been proposed (e.g., Azar and Sterner 1996; Sumaila and Walters 2005; Weitzman 1998; Newell and Pizer 2003, 2004). In addition, it is not clear that the same discount rate should be applied to all forms of capital and investment. For example, in most of the project level analysis in Asia the opportunity cost of capital is used as the basis for selecting the discount rate. But this rate might only apply to built capital investments relative to other built capital investments. It may not be appropriate to discount natural or social capital gains or losses at the same rate, or even with the same approach to discounting.

The general form for calculating the NPV is:

$$NPV = \sum_{t=0}^{\infty} V_t W_t \qquad (1)$$

Where:

V_t = the value of the service at time t

W_t = the weight used to discount the service at time t

For standard exponential discounting, W_t is exponentially decreasing into the future at the discount rate, *r*.

$$W_t = \left(\frac{1}{1+r}\right)^t \qquad (2)$$

Note that for a 0 percent discount rate, the value of equation 1 would be infinite, so one needs to put a time limit on the summation. A 0 percent discount rate would be justified if one assumes that, for social policy decisions, pure time preferences should be 0.

Another general approach to discounting argues that discount rates should not be constant, but should decline over time. There are two lines of argument supporting this conclusion. The first, due to Weitzman (1998) and Newell and Pizer (2003, 2004) argues that discount rates are uncertain and because of this, their average value should be declining over time. As Newell and Pizer (2003, 55) put it, "future rates decline in our model because of dynamic uncertainty about future events, not static disagreement over the correct rate, nor an underlying belief or preference for deterministic declines in the discount rate." A second line of reasoning for

declining rates is due to Azar and Sterner (1996), who first decompose the discount rate into a "pure time preference" component and an "economic growth" component. Those authors argue that, in terms of social policy, the pure time preference component should be set to 0 percent. The economic growth component is then set equal to the overall rate of growth of the economy, under the assumption that in more rapidly growing economies there will be more resources in the future and its impact on welfare will be marginally less, due to the assumption of decreasing marginal returns to income in a wealthier future society. If the economy is assumed to be growing at a constant rate into the indefinite future, this reduces to the standard approach to discounting, using the growth rate for *r*. If, however, one assumes that there are fundamental limits to economic growth, or if one simply wishes to incorporate uncertainty and be more conservative about this assumption, one can allow the assumed growth rate (and discount rate) to decline in the future.

Finally, a technique called "intergenerational discounting" (Sumaila and Walters 2005) should be mentioned. This approach includes conventional exponential discounting for the current generation, but it also includes conventional exponential discounting for future generations. Future generations can then be assigned separate discount rates that may differ from those assumed for the current generation. For the simplest case, where the discount rates for current and future generations are the same, this reduces to the following formula (Sumaila and Walters 2005, 139):

$$W_t = d^t + \frac{d * d^{t-1} * t}{G} \tag{3}$$

Where:

$$d = \frac{1}{1+r} \tag{4}$$

G = the generation time in years (25 for this example)

This method leads to significantly larger estimates of NPV than standard constant exponential discounting, especially at lower discount rates. At 1 percent the NPVs are five times as much, while at 3 percent they are more than double.

There is no clear and unambiguous reason for choosing one of the three methods over the others, or for choosing a particular discount rate, or for choosing the same method or discount rate for all the elements of a complex project. Newell and Pizer (2003) argue for a 4 percent discount rate, declining to approximately 0 percent in 300 years, based on historical data. One could argue that for ecosystem services, like fisheries and wetlands the starting rate should be even lower because natural capital is self-renewing and does not depreciate.

In the sensitivity analysis presented in a subsequent section, some of the BCA scenarios in the BDP2 were used as examples to compare the results using constant 10 percent, 3 percent, and 1 percent exponential discount rates, showing the range of results that this change can produce. It should be noted that this exercise is intended to show a range of possible results and the sensitivity to changing this parameter, not a prediction of future outcomes or an advocacy of any particular discount rate or approach to discounting. The lower discount rates were applied

only for the natural capital components of the project, since they are self-replicating and should not be seen as competing investments for human-made infrastructure like dams. Using the same logic, aquaculture was assessed at the original 10 percent discount rate since aquaculture requires investment and maintenance similar to competing built capital investments. The original BCA used a 50-year time frame. With a 10 percent, constant discount rate there is essentially no difference between this and an infinite time horizon. But for lower discount rates there is a major difference, so an infinite time horizon was used for the lower discount rates applied to natural capital. Lower discount rates might be appropriate also for other elements of renewable energy projects, like hydropower, but the purpose in this sensitivity analysis was to determine a reasonable range of results, not to investigate all possible approaches and assumptions.

The discussion above about alternative approaches to discounting should make clear, however, that the range of uncertainty is probably even greater than this sensitivity analysis suggests.

1.4. Scenario Analysis

The aim of the BDP scenarios is to evaluate the countries' water resources development policies and plans against agreed economic, environmental, and social objectives and criteria. The results, together with other basin-wide assessments (e.g., the SEA of the proposed LMB mainstream dams), provided a basis for discussion and negotiation of mutually beneficial levels of water resources development and their associated levels of transboundary environmental and social impacts. This led to a shared understanding of what could be considered as development opportunities, as described in the IWRM-based Basin Development Strategy.

The BDP scenarios were formulated to represent different combinations of nationally planned sector development, with a focus on water supply, irrigation, hydropower, and flood protection. These are sectors identified by the LMB countries as most important for future water resources development as well as having the greatest risk of transboundary environment and social impacts. The scenarios selected by LMB countries fall into four main categories: baseline, definite future situation, foreseeable future situation, and long-term future situation.

A complete description of the BDP2 scenarios is available in documents available on the MRC web site (http://www.mrcmekong.org/). This analysis used three main scenarios as case studies: (1) **Definite Future Scenario (DF):** 2015 Upper Mekong dams plus 26 additional hydropower dams in LMB and 2008 irrigation and flood measures; (2) **LMB 20-Year Plan Scenario with six mainstream dams in Northern Lao PDR:** 2015 Definite Future plus six LMB mainstream dams in upper LMB and 30 planned tributary dams, irrigation, and water supply. This scenario also includes climate change for an average year between 2010 and 2030 and 17cm sea level rise (hereafter referred to as the six dams scenario); and (3) **LMB 20-Year Plan Scenario with climate change:** 2015 Definite Future plus 11 LMB mainstream dams and 30 planned tributary dams, irrigation, and water supply. This scenario also includes climate change for an average year between 2010 and 2030 and 17cm sea level rise (hereafter referred to as the 11 dams scenario).

Note that each of these scenarios includes a range of water resource developments and other changes included in the national development plans, not only hydropower (although shorthand descriptions may be used that emphasize the number of dams as the main differences). In Table 14 and 21 of the BDP2 Main Report (Assessment of Basin-wide Development Scenarios) all the scenarios provided had negative outcomes for the overall assessment of severity of social and environmental impacts—a fact that should cause the governments concerned considerable doubt (MRC 2010a). These scenarios could be expanded, therefore, to cover a broader range of possible futures that would include positive environmental and social outcomes. This would be one way to address the "model uncertainty" mentioned above and would help to improve national planning processes as well. This approach is discussed in more detail further on in this report.

2. Fisheries and Other Ecosystem Services

Ecosystem services (ES) are the ecological characteristics, functions, or processes that directly or indirectly contribute to human well-being—the benefits people derive from functioning ecosystems (Costanza et al. 1997; MEA 2005). This definition is consistent with the one used in BDP2 and by the MRC more broadly. Ecosystem processes and functions may contribute to ecosystem services but they are not synonymous. Ecosystem processes and functions describe biophysical relationships and exist regardless of whether or not humans benefit (Granek et al. 2010). Ecosystem services, on the other hand, only exist if they contribute to human well-being and cannot be defined independently.

This report focuses on the services that the Mekong River provides to the population of the LMB through its fisheries and wetlands. These services include, but are not limited to, water supply, water flow regulation, waste treatment, flood protection, food production, raw material production, habitat refuges, recreation, and aesthetics.

This section of the report provides a summary of lessons learned from dams that have been constructed in other countries. It discusses the impacts on capture fisheries along with the risks and benefits of aquaculture as a replacement for lost capture fisheries. Finally, it discusses the losses in other ecosystem services from LMB dam construction.

2.1. Lessons from Mainstream Dams in Other Countries and Implications for the Mekong River

There is a large body of literature discussing the environmental effects of construction and operation of large dams in tropical river systems (e.g., Amazon Basin, Nile Delta, etc.). This section of the report provides a summary of many of the issues raised, with a specific focus on those that might be most relevant to the Mekong River system. The Mekong system is the second most biologically diverse river system after the Amazon and the freshwater fishery is the largest in the world.

Hydroelectric dams in the Amazon basin have halted long distance upstream migration of several species of catfish and interrupted the downstream migration of their larvae (Ribeiro et al. 1995). On the Araguaia-Tocantins River basin in Brazil, several species of catfish that

undergo long-distance migrations, have been drastically reduced as a result of multiple dams. This has caused the downstream catch to be reduced by as much as 70 percent (Berkamp et al. 2000) as a result of recruitment failure. According to the MRC Prior Consultation Project Review Report for the proposed Xayaburi hydropower project, there are at least 50 important migrant species in the lower Mekong River and a cascade of six dams would block 39 percent of the LMB's accessible habitat to migrant species from downstream (MRCS 2011).

Fish ladder efficiency in Brazil was studied by Godinho et al (1991) on the Tiguco River (upper Parana basin, southeastern Brazil). The ladder tested had 25 steps, was 78.3 m long and 10.8 m high. Of the 41 fish species captured in the region of the dam, 34 were present at the bottom of the fish ladder but only 2 percent of the species reached the upper section of the ladder.

As noted by Quiros (1989) when discussing fish passages in South America, "the fact that almost nothing is known of the swimming ability and migration behavior of the native species in developing countries, coupled with the lack of available data on their behavior means that it is impossible to establish broad guidelines regarding the most suitable fish pass designs." This conclusion is supported by recent assessments of hydroelectric development in the LMB (ICEM 2010b; MRCS 2011).

Fish passes have been developed mainly in North America and Europe for a very limited number of target species present in these countries, mainly salmonids which have remarkable jumping abilities that enable them to scale waterfalls and fish ladders more successfully than any other group of fish. These species are the only ones for which reliable, quantitative data exist on the effectiveness of passes. The situation is very different in other regions, in particular in South America, Asia, and Oceania. There are many migratory species whose biology, periods, and stages of migration are little known—or even completely unknown. On the Lower Mekong, fish passes will have to accommodate species of very different sizes, swimming ability, and migratory behavior, especially small catadromous species with limited swimming abilities (Ferguson et al. 2011).

The ability of many fish species to migrate downstream can also be adversely affected by hydroelectric dams and their impoundments, whether on the mainstream or on tributaries. Downstream migration of both adults and juveniles may be impeded or blocked and migration timing may be affected by the changes in flow regimes. Turbine-related mortalities are also an issue of concern (NWPPC 2009). While reliable data does not seem to be available for most tributary dams on the Mekong River, media reports indicate that the fish passage facilities at the disputed Pak Mun dam failed to provide adequate passage for many species.

On many large dams in tropical regions, fish passage devices have proven generally unsuitable for the species concerned. They are often undersized and not particularly well-suited to the rivers concerned. The attraction aspect of the passes has rarely been considered. A prerequisite for the construction of effective (qualitative concept) and efficient (quantitative concept) fish passage facilities is sufficient knowledge of the biology and behavior of the species concerned. Transposing fish passage technology to dam projects in other continents is difficult due to missing basic biological information. When design standards developed for temperate

zone fish are inappropriately applied to tropical conditions, failure is quite likely to occur. However, limited knowledge of the biology must not lead to the "do nothing" conclusion. In fact, it should lead to a conclusion to do more. Columbia River and Snake River projects have spent billions of dollars to fix the dams for fish bypass (and this only for a narrow species range). These fixes have included expensive juvenile bypass systems, barging of fish around structures and, finally, spilling a great deal of water that could be used for power production. It is very expensive to design and implement fish bypass measures after the dams are built (Ferguson et al. 2011).

Using an adaptive management approach (i.e., learning by doing) that explicitly treats actions as experiments could help fisheries managers to learn about the effectiveness of the proposed upstream and downstream passage systems. This type of approach has been used in the Columbia River basin and has resulted in increased effectiveness of both upstream and downstream passage of endangered salmonids (NWPPC 2009).

It is very important that fish passage design be at the forefront of any dam construction on the Lower Mekong. The dams should be designed and built with fish bypass plans that allows for adjustments and modifications that would reduce the cost of the adjustments for both upstream and downstream migration keeping in mind that adult migration and juvenile migration probably will require separate bypass facilities.

Fish pass design involves a multidisciplinary approach, including engineers, biologists, and managers. The fish pass technique is empirical in the original meaning of the term (i.e., based on feedback from the experience), and the most significant progress in fish passage technology has been made in North America and Europe where the effectiveness of the passes was systematically assessed and where it was obligatory to provide monitoring results (Marmula 2001). The priority is to acquire a better knowledge of fish communities, their biology, and their migratory behavior. This should be accomplished before the first dam is constructed. This knowledge should enable project designers to better define the objectives of a fish pass in a given river and to design more suitable devices.

However, it is also important to recognize the limits of the effectiveness of fish passage systems. These include indirect effects of dams such as changes in flow, water quality, increase in predation, and drastic changes to the habitat upstream or downstream. Complementary mitigation measures on flow management at certain times of the year, for example, could prove important to the long-term maintenance of a good balance in migratory fish populations. The protection of migratory species for a given dam must be studied in a much wider context than the strict respect of fish passages alone.

A major concern in Asia, especially in the LMB, is that dams will block movement of migratory fish along river courses. Additionally, dewatering or reduced flows in stream channels immediately downstream from dams can also be a serious problem (MRCS 2011). Reservoir yields in China are reported to range from 127 to 152 kg/ha/year, but these high values tend to be the result of intensive stocking programs. In India, reservoir fishery yields range from 11.4 (small reservoirs) to 49.5 (large reservoirs) kg/ha/year. Reservoir fishery yields in Southeast Asia (e.g., Malaysia), Central Asia, and Kazakhstan are reported to be much less than in other parts of Asia, with values typically around 15 kg/ha/year or less. Yields in Sri Lanka range

from 40 to 650 kg/ha/year, but these yields are primarily the result of stocking reservoirs with exotic species.

Other species are also affected by dams. For example, the land snail, *Anthinus albolabiatus,* which was formerly endemic to gallery forest adjacent to the Uruguay River, became extinct after construction of the Salto Grande Dam, in Uruguay (Seddon 2000). Overall mollusk species diversity is likely to be greatly reduced by damming (Seddon 2000). In the Lower Mekong, mollusks are abundant and widely harvested throughout regulated rivers, reservoirs, and other habitats in Thailand (ICEM 2010b).

A single dam and, more significantly, multiple dams along a river interfere with the genetic bridging function of the mainstream. Thus dams on the mainstream can influence species diversity in lateral tributaries, even though there may be no changes in water flow or quality characteristics. In the Murray River, Australia, river regulation has lead to the separation of oxbow lakes from the main channel habitat and thus has isolated many mollusks, in particular freshwater gastropods. Since river regulation was introduced some mollusk species have become extinct (McAllister et al. 2001). In the Lower Mekong system, mainstream dams will likely lead to the loss of productivity and biodiversity of migratory species that currently use tributary systems (ICEM 2010b).

In the Tennessee River Basin in the United States, several mollusks are under threat of global extinction following the construction of dams and the subsequent regulation of flow. The extirpation of freshwater mussel populations upstream of dam construction at Lake Pepin on the Mississippi River was due to the lost migratory fish host species, skipjack herring, *Alosa chrysochloris*, which the mussel larvae depended on for dispersal (Eddy and Underhill 1974).

The Nile Delta in Egypt has shrunk at a rate of 125 to 175 m/yr after the construction of the Aswan High Dam (Rozengurt and Haydock 1993) and more saline water has invaded inland. Saline water intrusion has been identified as a potential consequence of development and operation of mainstream dams on the Lower Mekong (ICEM 2010b). The effect of increased salinity on fishes of the Nile Delta has been documented by several authors. Abramovitch (1996), for example, notes that out of 47 commercial fish species in the Nile prior to the construction of the Aswan High Dam, only 17 were still harvested a decade after its completion. In 1907 about 72 species were identified in the Lower Nile (Boulenger 1907; McCallister et al. 2001). It was deduced that approximately 35 species have disappeared or have become very rare since the construction of the Aswan High Dam, other dams, and barrages in the Nile River. Although the system wide ecological impacts have not been well documented, this constitutes a nearly 50 percent reduction in the number of fish species.

The impoundment of the Nile River by the Aswan High Dam (1964) to create Lake Nasser/Nubia led to increased fish yields in the impounded section of the river, but due to trapping of nutrients in the impoundment that led to this productivity, there were declines in the pelagic fisheries in the entire eastern Mediterranean Sea (Ryder 1978).

2.2. Benefits and Risks of Aquaculture

Artificial production through aquacultural methods is often identified as the primary mitigation measure for loss of capture fisheries caused by the construction and operation of dams in the Mekong. However, there may be some uncertainty as to whether these types of efforts can be sustainable over the long-term (ICEM 2010).

Aquaculture practices have been rapidly expanding throughout the Mekong Basin. Most production in the upper countries is based on pond culture of primarily non-native species such as tilapia. In Viet Nam and Cambodia, the focus is primarily on cage culture of native giant snakehead and striped catfish, *Pangasius hypophthalmu*. A number of other non-native species are also raised for food purposes. At least 2 percent of the Mekong River fish species are non-native, most of which have escaped from aquaculture installations. Introduced species can disrupt habitats and consequently alter ecosystems to such a degree that native species are displaced. Several instances of this type of habitat disruption and species displacement have been identified as occurring in the Lower Mekong (Valbo-Jorgensen et al. 2009). Competition for resources between native and non-native species can be another potential difficulty. The extremely rapid expansion of alien species such as tilapia and other species with short life cycles and rapid growth is often characterized by stunting, where large numbers of small individuals compete with other more valuable species and reduce their numbers (Welcomme and Vidthayanon 2000).

Genetic concerns associated with aquaculture are focused on hybridization and the movement of localized native strains and varieties of fish around the basin. For example, the non-native African catfish, a species found in the Mekong River, hybridizes with native species. The extent to which other non-natives hybridize with natives is unknown. Interbreeding can pose risks to native species, particularly when it affects adaptive characteristics such as timing of migration and the ability to home to natal streams. Movement of native subpopulations and strains, without consideration of their origin, can cause similar problems. When inter-basin transfer of stocks occurs, the risks of the aforementioned effects are heightened. Accordingly, broodstock for production should be carefully selected from parental stock indigenous to the sub-basin where the aquaculture facility will be located.

For a number of species, aquaculture is based on taking of wild fry for broodstock, a common practice in parts of the Lower Mekong (Valbo-Jorgensen et al. 2009). Overharvest of these fry populations can lead to large declines or losses of other fish populations. Development of the river system could also lead to a decline in these populations with a corresponding impact on aquaculture production. It is also important to note that since a large proportion of the snakehead and catfish aquaculture production in the Lower Mekong is dependent on the so-called, lower-value trash fish for feeding, they are likely to be affected in the same manner. Additionally, the undifferentiated harvest of these species can lead to an unintended loss of biodiversity.

Unfortunately, there is no simple formula for addressing the impact of dams (positively or negatively) on riverine fisheries, although some recent watershed based assessment models such as Ecosystem Diagnosis and Treatment (Mobrand Biometrics 2004) and the Rapid Basin-

wide Hydropower Sustainable Development Tool (ADB et al. 2010) show promise. In certain cases, reservoir fisheries are great assets. For example, Sugunan (1997) reviewed fisheries in small impoundments within seven African, Asian, and Latin American/Caribbean countries. He reported that tilapia (exotic fishes), especially in island nations (e.g., Cuba and Sri Lanka) increased fish production in reservoirs. Marmulla (2001) concluded that this is most important in countries where river fisheries are small in comparison to overall national fishery yield and success in increasing fish yield from reservoir fisheries was observed when the number competing species and predators were few. In drier areas of a number of tropical countries, construction of reservoirs primarily for agricultural purposes often provides secondary benefits from fisheries.

2.3. Other Ecosystem Services

The Mekong River ecosystem provides a large range of ecosystem services to humans. The following sections discuss the impacts of LMB hydropower development on other ecosystem services including water flows and flood patterns, non-fish aquatic species, terrestrial species and cultural services, recognizing that other developments in the basin are also having adverse impacts and most of the proposed hydropower projects are on the tributaries.

2.3.1. Water Flows and Flood Patterns

Modifying water flows and flood patterns are the biggest threats to the ecology of floodplains. Once lost, the costs of rehabilitating the ecological functions of floodplains are very high. Any structure affecting water within a floodplain or in rivers upstream is assumed to have some influence on the floodplain environment and should be treated with caution. Most declines in fisheries production in tropical floodplains are either directly or indirectly related to changes in water flows. Seasonal flooding and connectivity are essential for maintaining the ecology of floodplains, a conclusion which is supported by numerous experiences in tropical floodplains in Asia, Africa, and South America (Baran et al. 2007).

The upper Mekong basin is the source of more than 50 percent of the suspended sediments in downstream areas of the LMB. If all planned dams were constructed it could create the potential to trap nearly all of the sediments. Loss of sediments in floodwater would result in a loss of natural soil fertility and lead to a loss of rice production or higher production costs due to increased use of fertilizers (Baran et al. 2007). It could also lead to increased erosion along the Mekong River's banks and to a lower survival rate for fish eggs dependent on shoreline habitats impacted by increased sedimentation smothering fish eggs. Permanent flooding of some areas could kill the flooded forests that are located along reservoir banks. These conditions are likely to be exacerbated in the Tonle Sap Lake region. However, it should be noted that sediment transport studies in the Mekong are fairly recent and some quantitative information is lacking.

Dams usually alter traditional riverine fisheries, sometimes positively (e.g., tailwater fisheries), but more commonly negatively. Often there are shifts from river-adapted species to those more adapted to lentic (lake-like) environments. Benefits from impoundment of rivers seem to be more pronounced for smaller, shallower reservoirs that have reasonably high concentrations of dissolved solids and that are located in the upper reaches of their respective

river ecosystem. However, several such impoundments within the same river catchment can result in synergistic negative impacts to the downstream fisheries. Introduction of exotic species (both in reservoirs and in tailwaters) can enhance yields, as long as the exotic fishes are environmentally sound and culturally acceptable to the surrounding human population (Marmulla 2001). Although management of dams can result in acceptable fisheries yields, when such management is focused solely on fisheries, specific needs of fish species not included in the fishery, or that may be threatened or endangered, are at risk of being overlooked. Detailed plans for addressing this type of problem are currently lacking in the development plans for the Lower Mekong. Planning documents imply that plans need to be developed to address these issues if planned mitigation actions are to be successful (ICEM 2010a).

If seasonal flood pulses are lost as a result of dams, there can be substantial losses to the fisheries of floodplain river ecosystems (Welcomme 1995; Junk et al 1989). Additionally, because dams tend to be constructed to enhance socioeconomic development activities, they tend to attract more people and industry. Subsequently, river ecosystems containing dams must contend with pollution, increased exploitation, and extraction of resources, pressures independent from, but adding to, the direct influences of dams and reservoirs on the physical and biological dimensions of the system. It is often difficult to separate the effect of dam construction from other perturbations to the ecosystem such as overfishing and pollution.

The control of floodwaters by large dams, which usually reduces flow during natural flood periods and increases flow during dry periods, leads to a discontinuity in river systems (e.g., changes in seasonal flows, nutrient levels and timing, temperature, etc.) and normally has a marked, negative impact on fish biodiversity.

The connection between the river and floodplain or backwater habitats is essential in the life history of many riverine fish that have evolved to take advantage of the seasonal floods and utilize the inundated areas for spawning and feeding. Loss of this connection can lead to extinction. In the Mekong system, a number of long-distance migrating species will likely be blocked from their native tributaries because of dam construction (ICEM 2010b).

Fish communities' productivity is reduced as the extent of land/water ecotones declines, resulting in a reduction in terrestrial food supply, spawning, and rearing habitats. This can occur in the floodplains below the dams as well as along the reservoir shoreline (the rise and fall of the reservoir often erodes the shoreline) and is accelerated by deforestation.

There is strong evidence that there is normally a significant positive relationship between freshwater flow and marine fish production (Berkamp et al. 2000). The effect is probably greatest in the first year of life. Fish abundance is normally determined during the egg and larval stages (Drinkwater and Frank 1994). Thus although the annual discharge through a hydropower dam may not differ much from unregulated flow, unless water is diverted, the seasonal timing of discharge may be significantly different, impacting marine fish negatively. Many marine fish spawn in estuaries or floodplains, generally at times of peak runoff. A decrease in freshwater flow and in nutrients may impact the nursery areas in a number of ways including increasing salinity and allowing predatory marine fish to invade.

There are very few examples of procedures management and restoration of regulated rivers. Stanford et al. (1996) give a general protocol for the restoration of regulated rivers that is premised on using dam operations to mimic natural temperature and flow regimes along with pollution abatement and control of exotic species to facilitate natural processes to restore damaged riverine habitat. They argue that careful management "letting the river do most of the work" can sustain biodiversity. Managers need to recognize the natural variability of rivers and explicitly incorporate them into overall ecosystem management strategies (Poff et al. 1997).

The spatial distribution of species is significantly modified after construction of impoundments due to factors such as predation. Barriers that enable small species to pass, but block larger fish from migration, can alter the ecology of rivers by reducing the biomass of predators at or near the top of the food web (Gehrke and Harris 2001). Fish migration is delayed for all class sizes at barriers with ineffective or no fishways and results in a concentration of migratory species in habitat favored by predatory species (Larinier 2001). This results in modified communities and altered biodiversity.

The loss of top predators can result in a cascade of effects on other animal and plant populations. While these trophic cascades are often hard to predict they tend to lead to a rise in more generalist and opportunistic species with a high reproductive rate relative to the larger predators. This occurrence, termed *mesopredator release*, often results in release of generalist predators with a capacity to reach high population densities and have large impacts on a wide range of prey species. These effects are not limited to the aquatic environment and can often have unintended consequences for terrestrial species. Ellis and others (2011) documented the major decline of wintering bald eagles in the Flathead Lake basin in Montana which was caused by the loss of the Kokanee salmon prey base precipitated by the introduction of opossum shrimp, *Mysis diluviana*, and the subsequent large increase in predatory lake trout. Recent studies in Panama (Galettiet et al. 2008) and Peru (Anderson et al. 2011) have demonstrated the importance of seed dispersal by fish in maintaining forest biodiversity, with larger fish dispersing them the greatest distance. The potential for trophic cascades in reservoirs is discussed in the MRC Prior Consultation Project Review Report for the Xayaburi project (MRCS 2011). More detailed information on the life histories of the indigenous terrestrial and aquatic species of the LMB that are likely to be impacted by dam construction and operation is needed.

Almost 50 percent of the Mekong riparian corridor is considered as Key Biodiversity Areas (KBAs) of global significance (ICEM 2010a) but poor management and lack of protected area zoning will see the continued degradation of the corridor over the next 30 years. More than 1,005 km of 2,040 km of the Lower Mekong (Chiang Saen to the sea) are identified as KBAs, but only about 100 km of the river actually lies within a nationally protected area.

As reported in the SEA of Hydropower on the Mekong Mainstream (ICEM 2010a), both biodiversity and stability for fisheries is expected to decrease despite some potential climate change benefits of increasing flooded area and nutrient loading. These decreases are attributed to the interactions among decreases in agricultural productivity resulting in greater pressure on fish populations, larger riparian populations, reduced fish migration and aquatic biodiversity attributed to the construction of dams and related infrastructure, and loss of habitat caused by climate change and development. While there may be some benefit to productivity from the

input of nutrients due to increased runoff and erosion with climate change these could be offset by sediment retention in upstream and tributary impoundments.

2.3.2. Non-fish Aquatic Species

The loss of habitats would encourage the proliferation of generalist species (both fish and other aquatic and terrestrial species) that can breed within the body of reservoirs and do not require specialized habitats or hydrological triggers to induce spawning.

The fragmentation of the river system by the 11 mainstream dams (and numerous tributary dams) would isolate aquatic populations into pockets leading to a loss of species (ICEM 2010b).

- **Mollusks**: The Mekong has the highest number of freshwater snails in the world. Many of these species would be threatened by the loss in habitat.
- **Amphibians**: Amphibians depend upon the wetland pools left by receding floodwaters for breeding. These species would be affected in all zones of the Mekong River
- **Irrawaddy dolphin**: The mainstream dams are likely to be the final threat leading to the extinction of the critically endangered Irrawaddy dolphin.
- **Siamese crocodiles**: Siamese crocodiles are found in the Stung Treng Ramsar site and possibly the Srepok River. This population of Siamese crocodiles could face local extirpation due to dams in this part of the river system.
- **Turtles**: Significant reduction in most species of turtles living in the Mekong, including the Cantor giant soft-shell turtle, due to loss of sandbars and seasonal breeding habitats.
- **Otters**: Mainstream dams would reduce the availability of suitable habitats and potentially fragment populations of otters living in the Mekong and Tonle Sap systems, including the three critical species: hairy-nosed otter (endangered), smooth-coated otter (vulnerable), and oriental small-clawed otter (vulnerable).

2.3.3. Terrestrial Species

Mainstream and tributary water resource development projects would impact terrestrial and aquatic biodiversity, which is of international significance given that about half the length of the Lower Mekong has been recognized as KBAs (ICEM 2010b).

- 80 percent of the KBAs along the Mekong River would be affected by proposed dams, with loss of landscape value, habitat diversity, and breeding and feeding areas for characteristic species, especially birds. River dependent bird species that rely on exposed sand bars and riverbanks for breeding and nesting would suffer from lost habitats. These likely could include the River Lapwings, and Pranticoles as well as various storks (painted and woolly necked), greater and lesser Adjutants, and ibises such as the Great Ibis, Black-shouldered Ibis, endangered River Terns, and the endemic Mekong wagtails.
- The globally important Siphandone wetlands would be directly affected with reduced seasonal variability and loss of wetland habitats.
- An international Ramsar site above Stung Treng would be directly affected. If the proposed Don Sahong dam is built, notification will be sent to the Ramsar Convention Secretariat that the Stung Treng site should be placed on the Montreux Record of threatened wetlands, with designation likely.

- The mainstream dams would make only a minor contribution to the reduction of flooded forest and wetland areas of the Tonle Sap.
- Poor or uncoordinated management of mainstream cascades could result in retention times in the order of several weeks, which would impact the timing and rate of transition between terrestrial and aquatic phases of the downstream flooded forests and wetlands.

3. Valuation of Changes in Ecosystem Services

3.1. Valuation Methodologies

Many ecosystem services described above are either public goods or common pool resources. Many of these are nonexcludable or difficult to exclude. Capture fisheries, for example are "provisioning services" that are often common pool resources since it is difficult to exclude fishers from accessing the resource. But fish, once caught, are rival (one person's use prevents others from benefiting) and nonrival. Many regulatory ecosystem services, such as flood regulation, are public goods that are both nonexcludable and nonrival (multiple users can simultaneously benefit from using them simultaneously). Regulatory services are generally not traded in markets (and probably should not be traded in markets). Therefore other methods are needed to assess their value. A number of methods can be used to estimate or measure benefits from ecosystems (Farber et al. 2002, 2006). In this report, replacement cost is used for calculating the value of the loss of capture fisheries and benefit transfer is used for the value of wetlands lost, which includes a full range of ecosystem services.

Using a replacement cost methodology is one means of indirectly estimating the value of ecosystem services. Replacement cost utilizes the value of the least expensive alternative to replace the services that the ecosystem currently provides. This report estimates how much it would cost to replace the net loss of capture fisheries using the price of fish (less fishing effort and less reservoir fisheries gain). In addition, as fish is the primary source of protein for much of the population, the cost of alternative protein sources was examined. This method provides an underestimate of the true value as it accounts for replacing only one portion of the service that capture fisheries provide—the physical livelihood of the population. It does not account for the cultural and social costs of lost fisheries. Aquaculture can potentially replace a part of the lost fisheries, but how effective this can be in the long run is highly uncertain.

To calculate the value of wetlands, benefit transfer was used as a means of determining the value of a hectare of wetland. Benefit transfer is the process of utilizing existing valuation studies or data to estimate the value of ecosystem services in one location and transfer them to value ecosystem services in a similar location. The transfer method involves obtaining an economic estimate for the value of nonmarket services through the analysis of a single study, or group of studies, that have been previously carried out to value similar services. The transfer itself refers to the application of values and other information from the original "study site" to a new "policy site" (Desvouges et al. 1998).

3.2. Ecosystem Service Values of the Mekong Basin

In this report, data from the BDP2 studies was used to calculate the cost of replacing capture

fisheries lost in the definite future scenario,[1] six dams scenario,[2] and the 11 dams scenario.[3] Methodologies include the replacement cost method to determine value of lost capture fisheries, alternative valuations of the lost ecosystem services from wetlands, and alternative discount rates for the natural capital components. Other gains and losses within each scenario were left as specified by the 2010 Assessment of Basin-wide Development Scenarios, Table 22 (BDP2) (MRC 2010a).

3.2.1. Fisheries

Within BDP2, sensitivity studies were conducted on fishery yields and on the supply-demand balance showing dramatically different outcomes in all scenarios. Best- and worst-case fishery yields from the BDP were used by this study to perform valuation of lost ecosystems within the LMB. Sensitivity studies can also be done on the values of the lost fisheries. Table 3.1 shows the capture fisheries lost and the NPV of capture fisheries, calculated using an infinite timeframe and various discount rates, with a specified replacement cost for a kilogram of fish. The infinite timeframe assumes that capture fisheries are natural capital which is self-replicating and there are minimal human investments needed to maintain the resource.[4] The observed change in NPV is due to a combination of both discount rate and fish price. Losses in fisheries production volumes per country and per scenario were taken directly from the BDP2 Scenario Summary Assessment spreadsheet (Table 101103).

The BDP2 studies estimated a net capture fisheries loss between 160,000 and 1.34 million tons, depending on the scenario. Looking at current fish prices in Southeast Asia and internationally, a replacement cost of $3.00/kg[5] was used, along with an assumption that capture fisheries by local fishers has very low effort and transport costs relative to commercial fish. This is one of the unpriced benefits of the provisioning ecosystem service of fish. The original BDP2 estimates used lower prices ($0.8/kg) partly because they subtracted the transport and fishing effort of commercial fish. To replace the benefits local fishers are currently receiving at their current location, however, one would have to incur these costs. The $3/kg value was used as an estimate of the replacement cost to set the range on the sensitivity analysis. In addition, the $3.00/kg replacement cost used is still probably a significant underestimate of the true value of the fish, since it does not take into account multipliers such as economic activity around the

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[1] **Definite Future Scenario (DF):** 2015-Upper Mekong dams plus 26 additional hydropower dams in LMB and 2008 irrigation and flood measures.

[2] **LMB 20-Year Plan Scenario with six mainstream dams in Northern Lao PDR:** 2015 Definite Future plus six LMB mainstream dams in upper LMB and 30 planned tributary dams, irrigation, and water supply. This scenario also includes climate change for average year between 2010 and 2030 and 17cm sea level rise.

[3] **LMB 20-Year Plan Scenario with climate change:** 2015 Definite Future plus 11 LMB mainstream dams and 30 planned tributary dams, irrigation, and water supply. This scenario also includes climate change for an average year between 2010 and 2030 and 17cm sea level rise.

[4] This assumption may be challenged on the basis that capture fisheries in the LMB are already under enormous threat from habitat destruction and pollution and therefore additional human investment is needed to maintain the fishery in a healthy state. However, for the purposes of our sensitivity analysis this represents a boundary condition.

[5] This estimate is based on two separate sources:

1. The average ex-vessel price of fish from Sumaila et al. (2007). This number is highly variable, changing over time and species from less than $1/kg to more than $4/kg.
2. The FAO Statistics estimates a world's value of production in 2008 in Asia for chicken to be between $1.77 and $5.18 per kilogram. They estimate pork to be between $1.72 and $6.44 per kilogram.

production of nets, processing and selling of fish, etc. Multiplying the tons of capture fisheries lost per year by this replacement cost, an alternative NPV of capture fisheries loss was derived for each scenario. The same replacement value was assumed for reservoir fisheries and aquaculture gains.

Table 3.1: The net present value (NPV) of capture fisheries lost at various discount rates with a specified replacement cost for a kilogram of fish

Net Total Capture Fisheries

	Country	Fisheries Production (Mtons/yr)	Fisheries Change (Mtons/yr)	replacement $/kg	NPV @ replacement cost (r=.1) ($millions)	NPV @ replacement cost (r=.03) ($millions)	NPV @ replacement cost (r=.01) ($millions)
Baseline	Lao PDR	0.25	0.00	$3.00	$0	$0	$0
	Thailand	0.92	0.00	$3.00	$0	$0	$0
	Cambodia	0.77	0.00	$3.00	$0	$0	$0
	Viet Nam	0.37	0.00	$3.00	$0	$0	$0
	Total	**2.30**	**0.00**		**$0**	**$0**	**$0**
Definite	Lao PDR	0.21	-0.04	$3.00	-$1,138	-$3,794	-$11,382
	Thailand	0.89	-0.03	$3.00	-$938	-$3,126	-$9,377
	Cambodia	0.71	-0.05	$3.00	-$1,618	-$5,392	-$16,175
	Viet Nam	0.34	-0.03	$3.00	-$1,034	-$3,445	-$10,335
	Total	**2.15**	**-0.16**		**-$4,727**	**-$15,757**	**-$47,270**
6 dams	Lao PDR	0.21	-0.04	$3.00	-$1,195	-$3,985	-$11,954
	Thailand	0.88	-0.04	$3.00	-$1,314	-$4,379	-$13,136
	Cambodia	0.63	-0.14	$3.00	-$4,222	-$14,075	-$42,224
	Viet Nam	0.31	-0.06	$3.00	-$1,811	-$6,038	-$18,114
	Total	**2.02**	**-0.28**		**-$8,543**	**-$28,476**	**-$85,429**
11 dams	Lao PDR	0.10	-0.14	$3.00	-$4,285	-$14,283	-$42,848
	Thailand	0.39	-0.53	$3.00	-$16,031	-$53,436	-$160,309
	Cambodia	0.32	-0.44	$3.00	-$13,344	-$44,479	-$133,437
	Viet Nam	0.16	-0.21	$3.00	-$6,436	-$21,453	-$64,360
	Total	**0.97**	**-1.34**		**-$40,095**	**-$133,651**	**-$400,953**

This NPV for the total net capture fisheries was calculated three times using three different discount rates (10 percent, 3 percent, and 1 percent, as discussed in Section 1). These results are shown in Table 3.1. Values ranged from -$4,727 million to -$40,095 million when the discount rate was kept at 10 percent (equal to the rate used in the BDP2) and the replacement cost was changed to $3.00/kg. When a 1 percent discount rate was used, the fisheries value decreased significantly from -$47,270 million to -$400,953 million, depending on scenario.

With the increase of dams, storage areas and the amount of reservoir fisheries will increase as well. Table 3.2 shows an increase of reservoir fisheries values from $454 million (Definite Future, 10 percent discount rate) to $78,175 million (11 dams, 1 percent discount rate). A comparison of the lost capture fisheries and the gained reservoir fisheries shows that reservoir fisheries will be able to replace between approximately 10 percent and 20 percent of the capture fisheries.

Table 3.2: The NPV of reservoir fisheries gain at various discount rates with a specified replacement cost for a kilogram of fish

Net Total Reservoir Fisheries

	Country	Reservoir Fisheries Production (Mtons/yr)	Reservoir Fisheries Change (Mtons/yr)	replacement $/kg	NPV @ replacement cost (r=.1) ($millions)	NPV @ replacement cost (r=.03) ($millions)	NPV @ replacement cost (r=.01) ($millions)
Baseline	Lao PDR	0.06429	0.00000	$3.00	$0	$0	$0
	Thailand	0.10600	0.00000	$3.00	$0	$0	$0
	Cambodia	0.02559	0.00000	$3.00	$0	$0	$0
	Viet Nam	0.02968	0.00000	$3.00	$0	$0	$0
	Total	**0.22556**	**0.00000**		**$0**	**$0**	**$0**
Definite	Lao PDR	0.07665	0.01236	$3.00	$371	$1,236	$3,707
	Thailand	0.10600	0.00000	$3.00	$0	$0	$0
	Cambodia	0.02616	0.00057	$3.00	$17	$57	$172
	Viet Nam	0.03189	0.00221	$3.00	$66	$221	$663
	Total	**0.24070**	**0.01514**		**$454**	**$1,514**	**$4,542**
6 dams	Lao PDR	0.10009	0.03580	$3.00	$1,074	$3,580	$10,741
	Thailand	0.10600	0.00000	$3.00	$0	$0	$0
	Cambodia	0.02616	0.00057	$3.00	$17	$57	$172
	Viet Nam	0.03291	0.00323	$3.00	$97	$323	$970
	Total	**0.26517**	**0.03961**		**$1,188**	**$3,961**	**$11,883**
11 dams	Lao PDR	0.18350	0.11921	$3.00	$3,576	$11,921	$35,764
	Thailand	0.19433	0.08833	$3.00	$2,650	$8,833	$26,500
	Cambodia	0.04797	0.02238	$3.00	$671	$2,238	$6,714
	Viet Nam	0.06034	0.03066	$3.00	$920	$3,066	$9,198
	Total	**0.48614**	**0.26058**		**$7,818**	**$26,058**	**$78,175**

In addition to reservoir fisheries, aquaculture is often seen as a primary mitigation measure for lost capture fisheries. The analysis in section 2, however, highlights some of the risks and difficulties of aquaculture. In the LMB, the majority of growth in aquaculture production would be in Viet Nam, creating a need for an extensive distribution network. The value of this replacement would not be distributed to the poor farmers but be centralized in specific areas of Viet Nam and with private companies. This would represent a significant loss to the poor populations of each of the four countries. For the purpose of sensitivity analysis, the calculations in this report therefore assumed that aquaculture could replace 50 percent or, as a worst case, 10 percent of the lost capture fisheries (as shown in Table 3.3). While the risks of aquaculture development may occur anyway, even if no additional dams are built, this is a separate issue from the sensitivity analysis. When discounting aquaculture, the original 10 percent discount rate applied to other built capital investments were assumed, since aquaculture, unlike natural capital, requires similar investment and maintenance to other built capital.

The results show that the combination of reservoir fisheries and increased aquaculture production, in aggregate, could replace the lost capture fisheries value, under certain economic assumptions but not under others. The losses and gains, however, may accrue to different groups of stakeholders, thus aggravating rather than alleviating poverty. It should also be noted that despite fish making up 70 percent of the protein intake there is still substantial malnutrition in poor communities in the LMB.

Table 3.3: The NPV of aquaculture gain at 10 percent discount rate and $3/kilogram of fish, assuming a 10 percent, 50 percent and BDP2 implied replacement of capture fisheries

	Net Total Aquaculture								
	Country	Aquaculture Production as stated in BDP2 (Mtons/yr)	Aquaculture Change w/10% fishery loss replacement (Mtons/yr)	Aquaculture Change w/50% fishery loss replacement (Mtons/yr)	Aquaculture Change w/BDP2 replacement (Mtons/yr)	replacement $/kg	NPV @ replacement cost (r=.1, replacement 10%) ($millions)	NPV @ replacement cost (r=.1, replacement 50%) ($millions)	NPV @ replacement cost (r=.1, replacement BDP2) ($millions)
Baseline	Lao PDR	0.07800	0.00000	0.00000	0.00000	$3.00	$0	$0	$0
	Thailand	0.10040	0.00000	0.00000	0.00000	$3.00	$0	$0	$0
	Cambodia	0.12711	0.00000	0.00000	0.00000	$3.00	$0	$0	$0
	Viet Nam	1.66336	0.00000	0.00000	0.00000	$3.00	$0	$0	$0
	Total	**1.96887**	**0.00000**	**0.00000**	**0.00000**		**$0**	**$0**	**$0**
Definite	Lao PDR	0.14987	0.00379	0.01897	0.07187	$3.00	$114	$569	$2,156
	Thailand	0.18216	0.00313	0.01563	0.08176	$3.00	$94	$469	$2,453
	Cambodia	0.16743	0.00539	0.02696	0.04032	$3.00	$162	$809	$1,210
	Viet Nam	2.49443	0.00345	0.01723	0.83107	$3.00	$103	$517	$24,932
	Total	**2.99388**	**0.01576**	**0.07878**	**1.02502**		**$473**	**$2,363**	**$30,751**
6 dams	Lao PDR	0.20377	0.00398	0.01992	0.12577	$3.00	$120	$598	$3,773
	Thailand	0.25881	0.00438	0.02189	0.15841	$3.00	$131	$657	$4,752
	Cambodia	0.24304	0.01407	0.07037	0.11593	$3.00	$422	$2,111	$3,478
	Viet Nam	3.32576	0.00604	0.03019	1.66240	$3.00	$181	$906	$49,872
	Total	**4.03138**	**0.02848**	**0.14238**	**2.06251**		**$854**	**$4,271**	**$61,875**
11 dams	Lao PDR	0.20377	0.01428	0.07141	0.12577	$3.00	$428	$2,142	$3,773
	Thailand	0.25881	0.05344	0.26718	0.15841	$3.00	$1,603	$8,015	$4,752
	Cambodia	0.24304	0.04448	0.22240	0.11593	$3.00	$1,334	$6,672	$3,478
	Viet Nam	3.32576	0.02145	0.10727	1.66240	$3.00	$644	$3,218	$49,872
	Total	**4.03138**	**0.13365**	**0.66826**	**2.06251**		**$4,010**	**$20,048**	**$61,875**

3.2.2. Wetlands

Wetlands provide critical services to inhabitants of the LMB such as water supply, water flow regulation, waste treatment, flood protection, food production, raw material production, habitat refuges, recreation, and aesthetics. Wetlands also provide a service to the international community through carbon sequestration and atmospheric composition regulation (Batker et al. 2010). Not all services provided by the ecosystem are included in this list, implying that most value estimates are conservative.

In this report, three different types of wetlands were valued: flooded forests, marshes, and inundated grassland (Table 3.4). Relative to the 2000 baseline, total wetland land cover change ranges from a decrease of 48,000 ha in the definite future scenario and an increase of 35,000 ha in the scenario with 11 dams built on the mainstream, as stated by the BDP2 (MRC 2010a). The wetland type that would be most negatively impacted would be the inundated grasslands, closely followed by marshes. In the scenarios with 11 dams, marshland area is increased most.

Values for each of the three different types of wetland are derived from a recent study done for the Mississippi Delta in the United States (Batker et al. 2008). The Mississippi study used the benefit transfer technique to determine the values of wetlands, based on a range of studies from around the world. The values transferred were all from climates and landscapes comparable to the Mississippi and the LMB. The Mississippi study found that flooded forests were valued at approximately $3,353/ha/yr, marshes at $3,305/ha/yr, and inundated grassland at $2,332/ha/yr. Using these figures, the total value of lost wetlands in the LMB ranged from -$993 million to +$1,061 million of gained wetland, with a 10 percent discount rate, depending on the scenario. On the other end of the sensitivity spectrum, a 1 percent discount rate produced a

value of $9,928 million of lost wetlands in the definite future scenario and a gain of $10,610 million in the 11 dam scenario. The large gain in the 11 dam scenario reflects the projected increase in wetlands from dam reservoir inundation and increased rainfall associated with climate change. The majority of the value lost in the definite future and 6 dam scenarios came from a loss of marshes, closely followed by inundated grasslands.

3.2.3. Total Value of Ecosystem Services

Table 3.5 is a recalculation of the total economic NPV in each scenario from the 2000 baseline by sector and country. The majority of the values were left as originally calculated in the BDP2. Four values were changed within the table: reservoir fisheries gain, aquaculture production, capture fisheries reduction, and wetland area reduction. Aquaculture gain was assumed to replace 10 percent of capture fisheries loss. The discount rates for aquaculture were not changed (10 percent in all cases) as they were for natural capital components to reflect the fact that aquaculture requires significant human investment and maintenance, similar to dams and other built capital.

When the revised figures are incorporated into the total NPV, using a 10 percent discount rate in the definite future, results in a positive net benefit value of $6,862 million, a decrease from $11,700 million in BDP2. Similar decreases in value are seen with a 10 percent discount rate for the other two scenarios: with 6 dams the value decreased from $26,729 million to $18,609 million, and with 11 dams from $33,403 million to $6,555 million. With a 1 percent discount rate, the overall NPV for the maximum development scenario would change from positive $33 billion to negative $274 billion. Figure 3.1 compares original and revised NPVs for the three scenarios under this sensitivity analysis. Figure 3.2 compares the components of the economic impacts for 10 percent, 3 percent, and 1 percent discount rates for each of the scenarios.

When looking at the economic losses that each of the individual countries would experience in the various scenarios, the two countries that lose most in every scenario are Thailand and Cambodia. Even when retaining a 10 percent discount rate, but using a replacement cost of $3.00/kg for capture fisheries, reservoir fisheries, and aquaculture, and the revised wetland values, Cambodia would have a loss of $895 million in the definite future and $6,509 million with 11 dams, while Thailand would have a gain of $251 million in the definite future but a loss of $7,256 million in the 11 dams scenario. Recalculating with a 3 percent discount rate, all countries would experience a NPV loss if the 11 dams scenario proceeded. With all three discount rates, Lao PDR has the largest gain in all three scenarios examined, although other social and environmental losses not included in the economic analysis may offset this economic gain.

Table 3.4: Three types of wetlands lost (flooded forests, marshes, and inundated grasslands) and the NPV at various discount rates

		Wetland area: flooded forests ('000ha)	Wetland loss: flooded forests ('000ha)	Wetland area: marshes ('000ha)	Wetland loss: marshes ('000ha)	Wetland area: inundated grassland ('000ha)	Wetland loss: inundated grassland ('000ha)	NPV ($millions)	forest: implied $/ha	marshes: implied $/ha	grassland: implied $/ha	forest: alternative $/ha	marshes: alternative $/ha	grassland: alternative $/ha
Baseline	Loa PDR	0	0.00	8.09	0.00	8.94	0.00	$0.00		$0	$0	$3,353	$3,305	$2,332
	Thailand	0	0.00	11.91	0.00	49.79	0.00	$0.00		$0	$0	$3,353	$3,305	$2,332
	Cambodia	452.35	0.00	517.85	0.00	317.55	0.00	$0.00	$0	$0	$0	$3,353	$3,305	$2,332
	Viet Nam	45.79	0.00	0.02	0.00	54.80	0.00	$0.00	$0	$0	$0	$3,353	$3,305	$2,332
	Total	**498.14**	**0.00**	**537.88**	**0.00**	**431.08**	**0.00**	**$0.00**						
Definite	Loa PDR	0	0.00	6.42	-1.68	5.75	-3.19	-$26.94		-$420	-$468	$3,353	$3,305	$2,332
	Thailand	0	0.00	10.07	-1.84	42.31	-7.47	-$47.48		-$472	-$112	$3,353	$3,305	$2,332
	Cambodia	450.11	-2.25	506.11	-11.74	310.55	-7.00	-$153.29	-$34	-$30	-$49	$3,353	$3,305	$2,332
	Viet Nam	45.74	-0.04	0.02	0.00	54.80	0.00	-$0.62	-$1	-$2,622	-$1	$3,353	$3,305	$2,332
	Total	**495.85**	**-2.29**	**522.62**	**-15.26**	**413.42**	**-17.66**	**-$228.33**						
6 dams	Loa PDR	0	0.00	6.16	-1.94	5.04	-3.91	-$18.45		-$300	-$366	$3,353	$3,305	$2,332
	Thailand	0	0.00	9.67	-2.24	40.84	-8.94	-$33.68		-$348	-$82	$3,353	$3,305	$2,332
	Cambodia	448.50	-3.86	501.36	-16.49	307.27	-10.28	-$124.83	-$28	-$25	-$41	$3,353	$3,305	$2,332
	Viet Nam	45.65	-0.13	0.02	0.00	54.80	-0.01	-$1.12	-$2	-$4,769	-$2	$3,353	$3,305	$2,332
	Total	**494.15**	**-3.99**	**517.21**	**-20.66**	**407.95**	**-23.13**	**-$178.09**						
11 dams	Loa PDR	0	0.00	7.50	-0.59	8.87	-0.07	-$3.16		-$42	-$36	$3,353	$3,305	$2,332
	Thailand	0	0.00	11.16	-0.75	46.66	-3.13	-$12.88		-$115	-$28	$3,353	$3,305	$2,332
	Cambodia	456.24	3.88	540.23	22.38	330.89	13.34	$119.84	$26	$22	$36	$3,353	$3,305	$2,332
	Viet Nam	45.79	0.00	0.02	0.00	54.76	-0.04	-$3.19	-$7	-$13,513	-$6	$3,353	$3,305	$2,332
	Total	**502.02**	**3.88**	**558.91**	**21.04**	**441.18**	**10.10**	**$100.61**						

		All wetlands: NPV @ alternative cost (r=.1) ($millions)	All wetlands: NPV @ alternative cost (r=.03) ($millions)	All wetlands: NPV @ alternative cost (r=.01) ($millions)	forest: NPV @ alternative cost (r=.1) ($millions)	forest: NPV @ alternative cost (r=.03) ($millions)	forest: NPV @ alternative cost (r=.01) ($millions)	marshes: NPV @ alternative cost (r=.1) ($millions)	marshes: NPV @ alternative cost (r=.03) ($millions)	marshes: NPV @ alternative cost (r=.01) ($millions)	grasslands: NPV @ alternative cost (r=.1) ($millions)	grasslands: NPV @ alternative cost (r=.03) ($millions)	grasslands: NPV @ alternative cost (r=.01) ($millions)
Baseline	Loa PDR	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Thailand	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Cambodia	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Viet Nam	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Total	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Definite	Loa PDR	-$130	-$433	-$1,298	$0	$0	$0	-$55	-$185	-$554	-$74	-$248	-$744
	Thailand	-$235	-$784	-$2,352	$0	$0	$0	-$61	-$203	-$609	-$174	-$581	-$1,743
	Cambodia	-$626	-$2,088	-$6,264	-$75	-$251	-$753	-$388	-$1,293	-$3,880	-$163	-$544	-$1,631
	Viet Nam	-$1	-$5	-$14	-$1	-$5	-$14	$0	$0	$0	$0	$0	$0
	Total	**-$993**	**-$3,309**	**-$9,928**	**-$77**	**-$256**	**-$767**	**-$504**	**-$1,681**	**-$5,043**	**-$412**	**-$1,373**	**-$4,118**
6 dams	Loa PDR	-$155	-$517	-$1,551	$0	$0	$0	-$64	-$213	-$640	-$91	-$304	-$911
	Thailand	-$283	-$942	-$2,826	$0	$0	$0	-$74	-$247	-$740	-$209	-$695	-$2,085
	Cambodia	-$914	-$3,046	-$9,138	-$129	-$431	-$1,292	-$545	-$1,816	-$5,449	-$240	-$799	-$2,396
	Viet Nam	-$5	-$16	-$47	-$4	-$15	-$45	$0	$0	$0	$0	-$1	-$2
	Total	**-$1,356**	**-$4,520**	**-$13,561**	**-$134**	**-$446**	**-$1,337**	**-$683**	**-$2,277**	**-$6,830**	**-$539**	**-$1,798**	**-$5,394**
11 dams	Loa PDR	-$21	-$70	-$211	$0	$0	$0	-$20	-$65	-$195	-$2	-$5	-$16
	Thailand	-$98	-$326	-$978	$0	$0	$0	-$25	-$83	-$248	-$73	-$243	-$730
	Cambodia	$1,181	$3,936	$11,809	$130	$434	$1,302	$740	$2,466	$7,397	$311	$1,037	$3,110
	Viet Nam	-$1	-$3	-$10	$0	$0	$0	$0	$0	$0	-$1	-$3	-$10
	Total	**$1,061**	**$3,537**	**$10,610**	**$130**	**$434**	**$1,302**	**$695**	**$2,318**	**$6,954**	**$235**	**$785**	**$2,354**

Table 3.5: Sensitivity of the total NPV to changing assumptions in each scenario from the 2000 baseline by sector and country Yellow highlighted rows are based on alternative assumptions about the value of capture and reservoir fisheries, aquaculture, and wetland ecosystem services.

	revised NPV @ replacement cost (r=.1) original BDP2 values at (r=.1) ($millions)			revised NPV @ replacement cost (r=.03) original BDP2 values at (r=.1) ($millions)			revised NPV @ replacement cost (r=.01) original BDP2 values at (r=.1) ($millions)		
	Definite Future	LMB 20-Year Plan Scenario with 6 mainstream dams in Northern Lao PDR	LMB 20-Year Plan Scenario Climate change (11 dams)	Definite Future	LMB 20-Year Plan Scenario with 6 mainstream dams in Northern Lao PDR	LMB 20-Year Plan Scenario Climate change (11 dams)	Definite Future	LMB 20-Year Plan Scenario with 6 mainstream dams in Northern Lao PDR	LMB 20-Year Plan Scenario Climate change (11 dams)
Hydropower generated	$11,491	$25,002	$32,823	$11,491	$25,002	$32,823	$11,491	$25,002	$32,823
Irrigated agricultural production	$0	$1,659	$1,659	$0	$1,659	$1,659	$0	$1,659	$1,659
Reservoir fisheries (original)	$91	$132	$215	$91	$132	$215	$91	$132	$215
Reservoir fisheries (revised)	$454	$1,188	$7,818	$1,514	$3,961	$26,058	$4,542	$11,883	$78,175
Aquaculture production (orginal)	$1,129	$1,261	$1,261	$1,129	$1,261	$1,261	$1,129	$1,261	$1,261
Aquaculture production (revised)	$473	$854	$4,010	$473	$854	$4,010	$473	$854	$4,010
Capture fisheries reduction (original)	-$946	-$952	-$1,936	-$946	-$952	-$1,936	-$946	-$952	-$1,936
Capture fisheries reduction (revised)	-$4,727	-$8,543	-$40,095	-$15,757	-$28,476	-$133,651	-$47,270	-$85,429	-$400,953
Wetland area reduction (original)	-$228	-$178	$101	-$228	-$178	$101	-$228	-$178	$101
Wetland area reduction (revised)	-$993	-$1,356	$1,061	-$3,309	-$4,520	$3,537	-$9,928	-$13,561	$10,610
Reduction in eco-hotspot/biodiversity	-$85	-$240	-$415	-$85	-$240	-$415	-$85	-$240	-$415
Forest area reduction	-$153	-$228	-$372	-$153	-$228	-$372	-$153	-$228	-$372
Recession rice	-$144	-$175	$278	-$144	-$175	$278	-$144	-$175	$278
Flood damage mitigation	$462	$360	-$273	$462	$360	-$273	$462	$360	-$273
Mitigation of salinity affected areas	$20	$23	-$2	$20	$23	-$2	$20	$23	-$2
Losses in bank erosion areas	$0	$0	$0	$0	$0	$0	$0	$0	$0
Navigation	$64	$64	$64	$64	$64	$64	$64	$64	$64
Total economic impacts (original)	**$11,700**	**$26,729**	**$33,403**	**$11,700**	**$26,729**	**$33,403**	**$11,700**	**$26,729**	**$33,403**
Total economic impacts (revised)	**$6,862**	**$18,609**	**$6,555**	**-$5,424**	**-$1,716**	**-$66,284**	**-$40,528**	**-$59,787**	**-$274,396**
Lao PDR (original)	$6,595	$17,636	$22,604	$6,595	$17,636	$22,604	$6,595	$17,636	$22,604
Lao PDR (revised)	$5,761	$17,283	$22,111	$3,667	$16,638	$20,409	-$2,315	$14,796	$15,546
Thailand (original)	$1,095	$3,913	$4,445	$1,095	$3,913	$4,445	$1,095	$3,913	$4,445
Thailand (revised)	-$54	$2,280	-$7,625	-$2,791	-$1,444	-$39,076	-$10,610	-$12,086	-$128,934
Cambodia (original)	$693	$1,351	$2,628	$693	$1,351	$2,628	$693	$1,351	$2,628
Cambodia (revised)	-$1,200	-$3,098	-$6,879	-$6,395	-$15,043	-$33,692	-$21,240	-$49,169	-$110,302
Viet Nam (original)	$3,317	$3,828	$3,727	$3,317	$3,828	$3,727	$3,317	$3,828	$3,727
Viet Nam (revised)	$2,354	$2,145	-$1,052	$94	-$1,867	-$13,925	-$6,363	-$13,328	-$50,706
Total (original)	**$11,700**	**$26,728**	**$33,404**	**$11,700**	**$26,728**	**$33,404**	**$11,700**	**$26,728**	**$33,404**
Total (revised)	**$6,862**	**$18,609**	**$6,555**	**-$5,424**	**-$1,716**	**-$66,284**	**-$40,528**	**-$59,787**	**-$274,396**

Figure 3.1 Comparison of original and revised NPVs for the three scenarios assuming 10 percent, 3 percent, and 1 percent discount rates under the sensitivity analysis

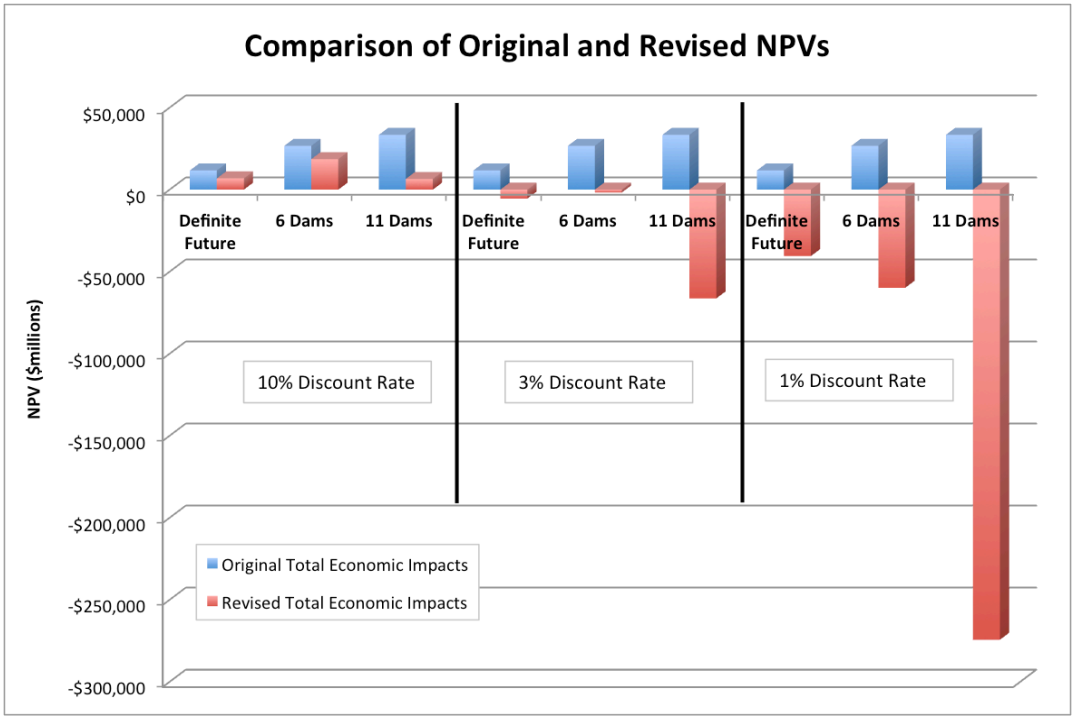
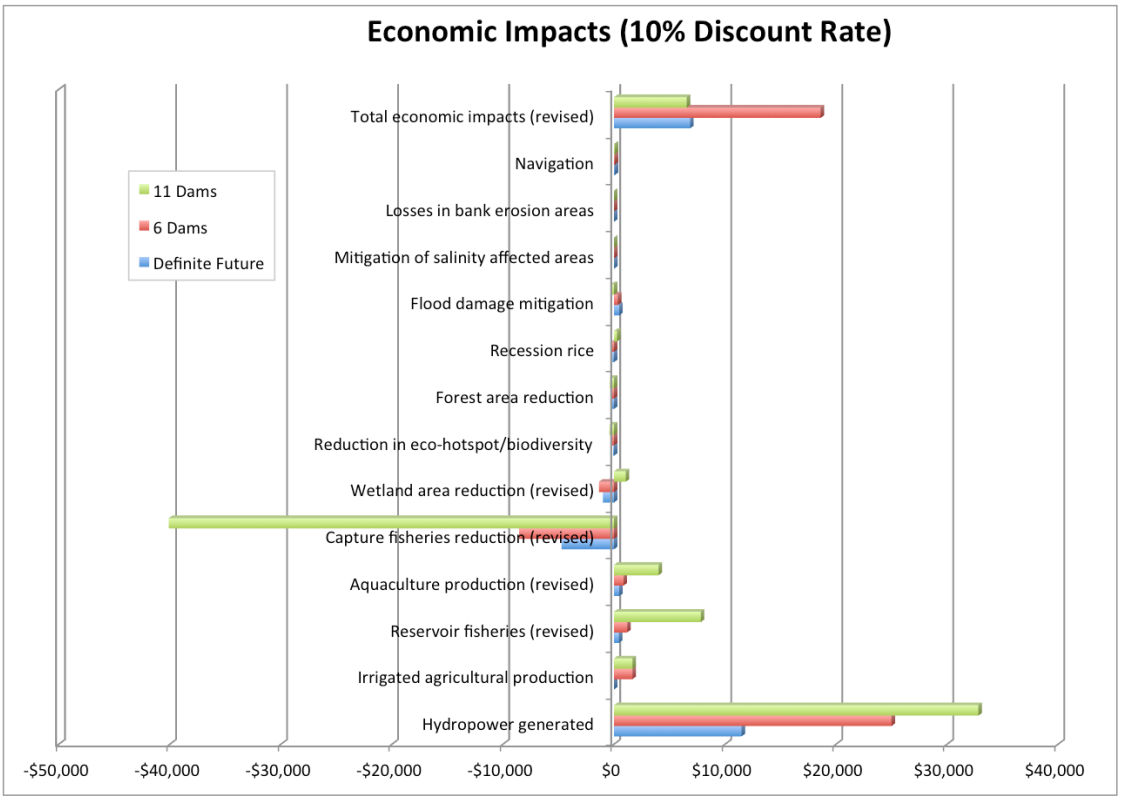
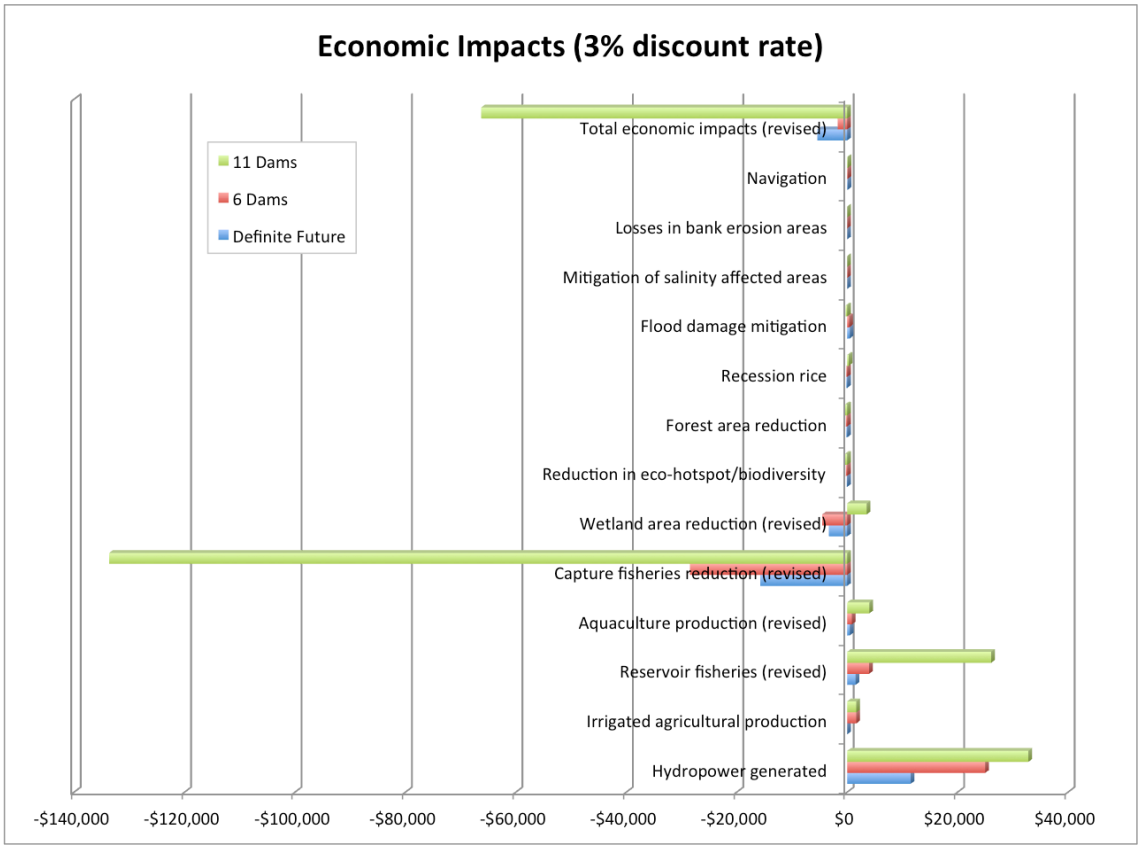
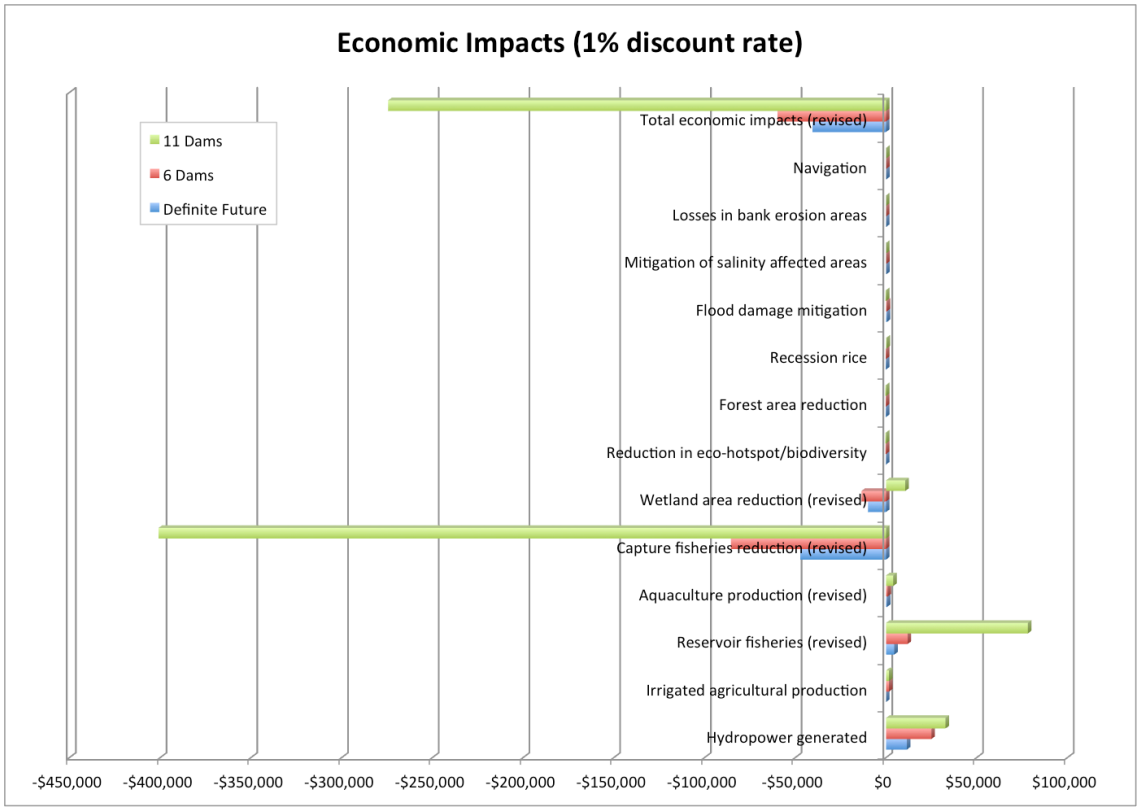


Figure 3.2 Comparison of components of the economic impacts at 10 percent, 3 percent and 1 percent discount rates for the three scenarios under the sensitivity analysis




Economic Impacts (3% discount rate)
11 Dams
6 Dams
Definite Future
Total economic impacts (revised)
Navigation
Losses in bank erosion areas
Mitigation of salinity affected areas
Flood damage mitigation
Recession rice
Forest area reduction
Reduction in eco-hotspot/biodiversity
Wetland area reduction (revised)
Capture fisheries reduction (revised)
Aquaculture production (revised)
Reservoir fisheries (revised)
Irrigated agricultural production
Hydropower generated
-$140,000
-$120,000
-$100,000
-$80,000
-$60,000
-$40,000
-$20,000
$0
$20,000
$40,000


Economic Impacts (1% discount rate)
11 Dams
6 Dams
Definite Future
Total economic impacts (revised)
Navigation
Losses in bank erosion areas
Mitigation of salinity affected areas
Flood damage mitigation
Recession rice
Forest area reduction
Reduction in eco-hotspot/biodiversity
Wetland area reduction (revised)
Capture fisheries reduction (revised)
Aquaculture production (revised)
Reservoir fisheries (revised)
Irrigated agricultural production
Hydropower generated
-$450,000
-$400,000
-$350,000
-$300,000
-$250,000
-$200,000
-$150,000
-$100,000
-$50,000
$0
$50,000
$100,000

4. Improved Integration in an Evolving Planning Process

4.1. Improved Integrated Systems Modeling

The BDP2 was based on a fairly conventional, static, linear, benefit/cost analysis. New understanding about system dynamics and predictability that has emerged from the study of complex systems is creating new tools for modeling the dynamic interactions between human and natural systems. A range of techniques have become available through advances in computer speed and accessibility, and by implementing a broad, interdisciplinary systems view (Costanza et al. 1993; Costanza and Ruth 1998; Boumans et al. 2002; Costanza and Voinov 2003).

Systems are groups of interacting, interdependent parts linked together by exchanges of energy, matter, and information. *Complex* systems are characterized by: (1) strong (usually nonlinear) interactions between the parts; (2) complex feedback loops that make it difficult to distinguish cause from effect; and (3) significant time and space lags, discontinuities, thresholds and limits; all resulting in (4) the inability to simply "add up" or aggregate small-scale behavior to arrive at large-scale results (von Bertalanffy 1968; Rastetter et al. 1992). Ecological and economic systems both independently exhibit these characteristics of complex systems. Taken together, linked ecological economic systems are devilishly complex.

While almost any subdivision of the universe can be thought of as a system, modelers of systems usually look for boundaries that minimize the interaction between the system under study and the rest of the universe in order to make their job easier. However, the interactions between ecological and economic systems are many and strong. So, while splitting the world into separate economic and ecological systems is possible, it does not minimize interactions and is a poor choice of boundary.

Most scientific disciplines tend to dissect their subject into smaller and smaller isolated parts in an effort to reduce the problem to its essential elements. In order to allow the dissection of system components, it must be assumed that interactions and feedbacks between system elements are negligible or that the links are essentially linear so they can be added up to give the behavior of the whole (von Bertalanffy 1968). Complex systems violate the assumptions of reductionist techniques and therefore are not well understood using the perspective of classical science. In contrast, *systems analysis* is the scientific method applied across many disciplines, scales, resolutions, and system types in an integrative manner.

In economics, for example, a typical distinction is made between partial equilibrium analysis (the type used in the BDP2) and general equilibrium analysis. In partial equilibrium analysis, a subsystem (i.e. a single market or scenario) is studied with the underlying assumption that there are no important feedback loops. "All else being equal" is the usual assumption. In general equilibrium analysis, on the other hand, the totality of markets and their interactions are studied in order to bring out the general interdependence in the economy. The large-scale, whole economy, general equilibrium effects are usually quite different from the sum of the constituent small-scale, partial equilibrium effects. Add to this the further complication that in

reality equilibrium is never achieved, and one can begin to see the limitations of classical, reductionist science in understanding complex systems like the LMB.

To incorporate this understanding, analysis needs to shift away from implicit assumptions that eliminate links within and between economic and natural systems, because, due to the strength of the real world interactions between these components, failing to link them can cause severe misperceptions and indeed policy failures (Costanza 1987).

To achieve a comprehensive understanding that is useful for modeling and prediction of linked ecological economic systems requires the synthesis and integration of several different conceptual frames. As Levins (1966) has described this search for robustness, "we attempt to treat the same problem with several alternative models each with different simplifications… Then, if these models, despite their different assumptions, lead to similar results we have what we call a robust theorem which is relatively free of the details of the model. Hence our truth is the intersection of independent lies."

Existing modeling approaches can be classified according to a number of criteria, including scale, resolution, generality, realism, and precision. The most useful approach within this spectrum of characteristics depends on the specific goals of the modeling exercise. A few examples of how one might match model characteristics with several of the possible modeling goals relevant for ecological economic systems are described below. A better appreciation of the range of possible model characteristics and goals can help to more optimally match characteristics and goals.

Complex systems analysis offers great potential for generating insights into the behavior of linked ecological economic systems. These insights will be needed to achieve a sustainable pattern of human development, a pattern that works in synergy with the life-supporting ecosystems on which it depends. Transdisciplinary collaboration and cooperative synthesis among natural and social scientists and others will be essential (Norgaard 1989).

This approach is certainly not simple or easy. However it could be applied in the LMB in a number of ways, using currently available data. For example, Costanza and Voinov (2003) provide some background and several case studies of landscape scale, integrated simulation modeling that may be applicable to the LMB situation. One example was a spatially explicit, process-based model for the Patuxent river watershed in Maryland (Costanza et al. 2002). This model was designed to integrate data and knowledge over several spatial, temporal, and complexity scales, and to serve as an aid to regional management. In particular, the model addresses the effects of both the magnitude and spatial patterns of human settlements and agricultural practices on hydrology, plant productivity, and nutrient cycling and other ecosystem services in the landscape. The spatial resolution is variable, with a maximum of 200m x 200m to allow adequate depiction of the pattern of ecosystems and human settlement on the landscape. The temporal resolution is different for various components of the model, ranging from hourly time steps in the hydrologic sector to yearly time steps in the economic land use transition module.

A more participatory "mediated modeling" approach to model development might also be extremely useful to help build consensus and a shared understanding of the complex systems involved (cf. Costanza and Ruth 1998; van den Belt 2004).

4.2. Broader Scenario Planning

BDP scenarios were formulated to represent different combinations of current and future multiple uses of the Mekong River as planned by LMB governments. The scenarios were assessed to evaluate their net economic and social benefits to provide a basis for discussion, which informed the IWRM-based Basin Development Strategy. Above, some of the general sources of uncertainty in this sort of analysis were discussed and some additional parameter sensitivity analysis on these scenarios was presented to deal with the parameter uncertainty source. One way to deal with the model uncertainty source is the use of multiple models with alternative assumptions, as discussed briefly above. Another, complementary way to do this is with a broader spectrum of scenarios, using an approach called "scenario planning." Scenario planning looks at alternative *plausible* futures considering a broad range of drivers and uncertainties. These scenarios can embody alternative models and assumptions as one way to deal with model uncertainty.

Predicting the future is impossible. But we can lay out a series of plausible scenarios, which help to better understand future possibilities and the uncertainties surrounding them. As Nicholls et al. (2011) put it, "Scenarios enable decision makers to consider a variety of plausible storylines of how the future might unfold and are exploratory tools where factors shaping the future are especially uncertain or the complex nature of systems makes them unpredictable." They have become an important way to inform decision-making under uncertainty.

Scenario is a term with multiple meanings. Scenario exercises vary in their objectives and hence their characteristics (Biggs et al. 2007; Nicholls et al. 2011). *Scenario analysis* or *scenario planning* is defined here as a structured process of exploring and evaluating the future. Scenarios are essentially stories that consider how alternative futures, typically related to a particular focal issue (O'Brien 2000), may unfold from combinations of highly influential and uncertain drivers, and their interactions with more certain driving forces.

Scenario planning differs from forecasting, projections, and predictions, in that it explores *plausible* rather than *probable* futures (Peterson et al. 2003). Although aspects of the future worlds depicted by scenarios may come to eventuate, these worlds are often best viewed as caricatures of reality from which we can learn.

Scenario planning is based on four assumptions (DTI 2003):

1. The future is unlike the past, and is significantly shaped by human choice and action.
2. The future cannot be foreseen, but exploring possible futures can inform present decisions.
3. There are many possible futures; scenarios therefore map within a "possibility space."
4. Scenario development involves both rational analysis and creative thinking.

Scenarios are best suited to exploring situations of high uncertainty and low controllability (Peterson et al. 2003). For example, climate change and global governance are largely beyond

the control of a particular region. In these situations, scenarios can help to illuminate the consequences of these uncontrollable forces and to formulate robust responses locally. Importantly, scenarios can help to reveal policy and value changes that may be required, and key branching points at which such changes can most affect outcomes (Gallopín 2002). Several scenario planning exercises have been conducted in recent years at a range of spatial scales and for a range of purposes, including: global futures (Gallopin et al. 1997; Nakićenović and Swart 2000; Raskin et al. 2002; Millennium Ecosystem Assessment 2005), regional futures (European Environmental Agency 2009), corporate strategy (Wack 1985; Shell International 2003), political transition (Kahane 1992, 2004) and community-based natural resource management (Wollenberg et al. 2000; Evans et al. 2006). For example, the *Special Report on Emissions Scenarios* (SRES) (Nakićenović and Swart 2000) has been widely used to study the potential impacts of future climates, especially within the Intergovernmental Panel on Climate Change (IPCC) process.

Potential scenarios for the LMB could compare the conventional development model underlying the set of scenarios already produced, with an alternative development model based on a broader conception of sustainable human well-being (cf. Costanza 2008). Table 4.1 highlights the main differences between these models. This would allow the full range of plausible futures to be explored. For example, all scenarios explored in the BDP2 had negative social and environmental impacts. These essential elements of human well-being should be given more weight and scenarios developed that provide positive outcomes in these elements.

A scenario planning exercise such as this is not particularly expensive to implement, and yet can yield significant payoffs. It should be implemented in a way that allows participation from a broad range of stakeholders and leads to a better-shared understanding of the choices involved. The process consists of three general steps:

1. Generate scenarios. This effort can be performed by a core group that facilitates a series of stakeholder focus group meetings, with participants specifically selected to represent major topic areas to be addressed. Scenario exercises often begin by defining two major axes of uncertainty about the future (e.g., the economic versus environmental concerns and the global versus regional or national development patterns axes that were used in the IPCC's SRES scenarios). Once the axes are determined, the overriding or driving characteristics of plausible futures are created, tested, and refined through iterative dialogues with the focus groups. The descriptions of plausible futures include the relevant elements of the system, driving forces that will define the future, and the early indicators for the unfolding, or realization, of each scenario. For example, a "business as usual" scenario describes what the continuation of current trends will look like into the future (cultural conditions, environmental health, transportation and energy infrastructure, etc.), the economic and political forces that will drive that future, and what the indicators will be over time that signal the path to that future.

2. Evaluate scenarios. For each scenario, an evaluation in some detail of the characteristics of that scenario is developed. What does that future look and feel like? What would it be like to live in? This may include variables such as ecosystem services, housing, employment, transportation, energy, quality of life, etc. Narrative descriptions, maps, and visualizations of each scenario can be developed to provide meaning and clarity to what that future might mean to individuals and countries. Each scenario's resilience in the face of low probability, high impact

events, such as earthquakes, floods, or dam failures, can also be evaluated and displayed. Public surveys can be used to test public preferences for each of the scenarios. The result is a quantitative assessment of public and stakeholder preferences for each scenario and of how the public evaluates tradeoffs between the scenarios and their respective attributes and limitations.

3. Provide direction on how to get there. After the preferred scenarios are further refined, described, and evaluated (based on additional public reviews and stakeholder discussions), specific plans and recommendations for public and private institutions can be developed that would substantively move the system toward the preferred future scenario.

Table 4.1: Alternative development models (from Costanza 2008)

A New Development Model

	Current Development Model: the "Washington Consensus"	Sustainable Development Model: an emerging "Green Consensus"
Primary policy goal	More: Economic growth in the conventional sense, as measured by GDP. The assumption is that growth will ultimately allow the solution of all other problems. More is always better.	Better: Focus shifts from mere growth to "development" in the sense of improvement in quality of life, recognizing that growth has negative by-products and more is not always better.
Primary measure of progress	GDP.	GPI (or something similar).
Scale/carrying capacity	Not an issue because it is assumed that markets can overcome any resource limits via new technology, and substitutes for resources are always available.	A primary concern as a determinant of ecological sustainability. Natural capital and ecosystem services are not infinitely substitutable, and real limits exist.
Distribution/poverty	Lip service, but relegated to "politics" and a "trickle down" policy: A rising tide lifts all boats.	A primary concern since it directly affects quality of life and social capital and in some real ways is often exacerbated by growth.
Economic efficiency/ allocation	The primary concern, but generally including only marketed goods and services (GDP) and institutions.	A primary concern, but including both market and non-market goods and services and effects. Emphasizes the need to incorporate the value of natural and social capital to achieve true allocative efficiency.
Property rights	Emphasis on private property and conventional markets.	Emphasis on a balance of property rights regimes appropriate to the nature and scale of the system, and a linking of rights with responsibilities. A larger role for common property institutions in addition to private and state property.
Role of government	To be minimized and replaced where possible with private and market institutions.	A central role, including new functions as referee, facilitator, and broker in a new suite of common-asset institutions.
Principles of governance	*Laissez-faire* market capitalism.	Lisbon principles of sustainable governance.

Basic characteristics of the current development model and an emerging model based on sustainable "ecological economics."

Great Transition Initiative Scenarios

A relevant example of scenario planning is the Great Transition Initiative, an ongoing effort with its beginnings in the 1990s (Gallopín et al. 1997) (http://gtinitiative.org/). The scenarios have changed name and number over time, but the current set involves four major scenarios: market forces, policy reform, fortress world, and great transition. These scenarios have been very well developed at both the global and regional levels. A brief summary of the four scenarios is given below. More details are given at http://gtinitiative.org. Although these scenarios are not specifically recommended for use in the LMB, they are offered as one relatively well worked-out example of the process.

The *market forces* scenario is a story of a market-driven world in the twenty-first century in which demographic, economic, environmental, and technological trends unfold without major surprise relative to unfolding trends. Continuity, globalization, and convergence are key characteristics of world development – institutions gradually adjust without major ruptures, international economic integration proceeds apace, and the socioeconomic patterns of poor regions converge slowly toward the development model of the rich regions. This is the general scenario within which the BDP2 scenarios fall (perhaps with some elements of the policy reform scenario as well). A broader look at other plausible futures would include all four scenarios.

The *policy reform* scenario envisions the emergence of strong political will for taking harmonized and rapid action to ensure a successful transition to a more equitable and environmentally resilient future. It explores the requirements for simultaneously achieving social and environmental sustainability goals under high economic growth conditions similar to those of the market forces scenario.

The *fortress world* scenario is a variant of a broader class of Barbarization scenarios, in the hierarchy of the Global Scenario Group (Gallopín et al. 1997). Barbarization scenarios envision the grim possibility that the social, economic, and moral underpinnings of civilization deteriorate as emerging problems overwhelm the coping capacity of both markets and policy reforms.

The *great transition* scenario explores visionary solutions to the sustainability challenge, including new socioeconomic arrangements and fundamental changes in values. This scenario depicts a transition to a society that preserves natural systems, provides high levels of welfare through material sufficiency and equitable distribution, and enjoys a strong sense of local solidarity. This scenario envisions a world like the one outlined in the "green consensus" of Table 4.1.

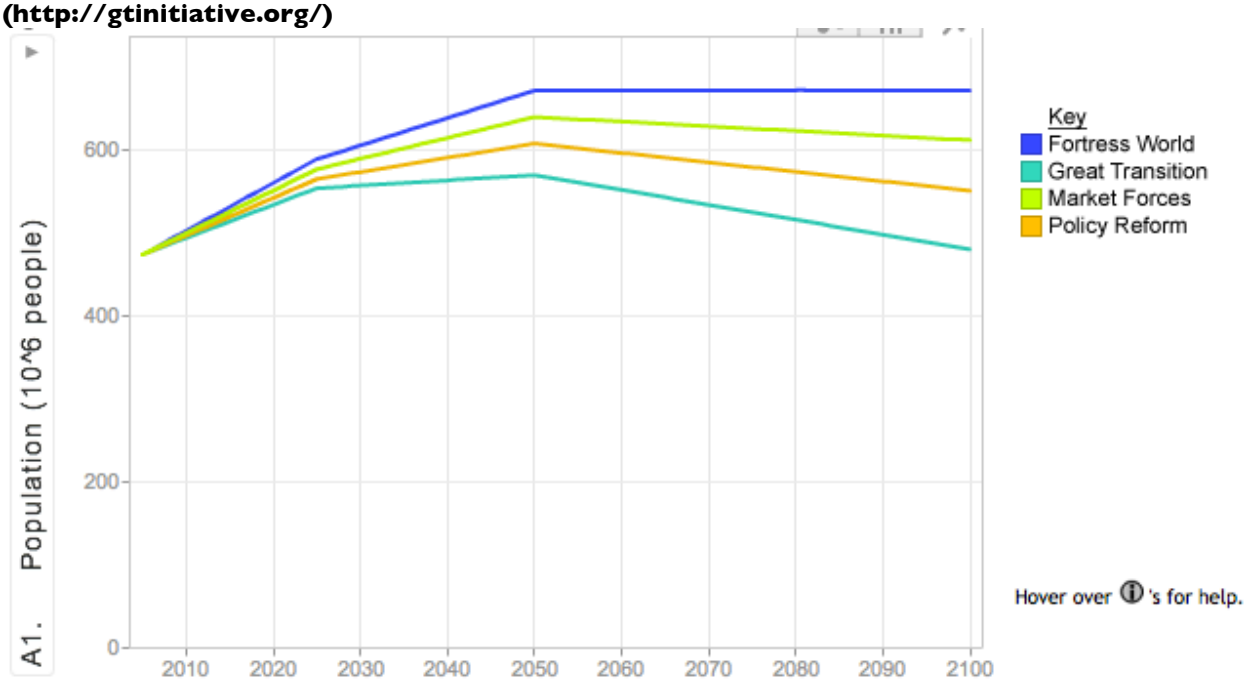
An interactive web site allows users to visualize and explore the scenarios (http://www.tellus.org/results/results_World.html). The descriptions of these scenarios in the published books and websites are probably the most extensive of any existing scenario exercise. The status and trends of over 40 variables are plotted for each scenario, including several variables related to ecosystem services (e.g., carbon emissions, water use, forested area) and an overall "Quality of Development Index" that is similar in structure to the Genuine Progress Indicator (GPI) and other indices of societal well-being. The scenarios are also broken down into geographic regions, including Southeast Asia. Figure 4.1 shows a few selected indicators for these four scenarios for Southeast Asia from the GTI web site.

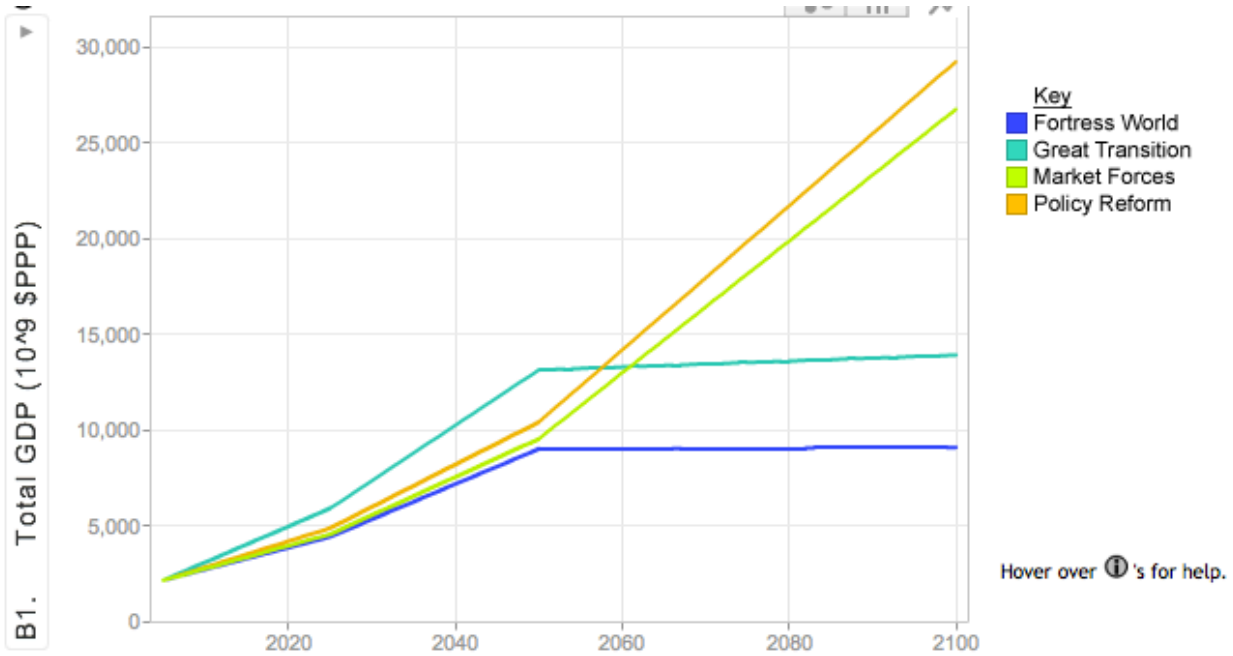
Figure 4.1 shows, for example, that while population stabilizes in all scenarios, GDP increases most in the market forces and policy reform scenarios, and overall quality of development is highest in the great transition scenario, along with lower carbon emissions. Fortress world is obviously the scenario to be avoided, as it entails higher population, lower income, lower quality of development, and higher carbon emissions. Sustainable policies can be thought of as those that maximize the chances of avoiding this scenario given the uncertainties involved.

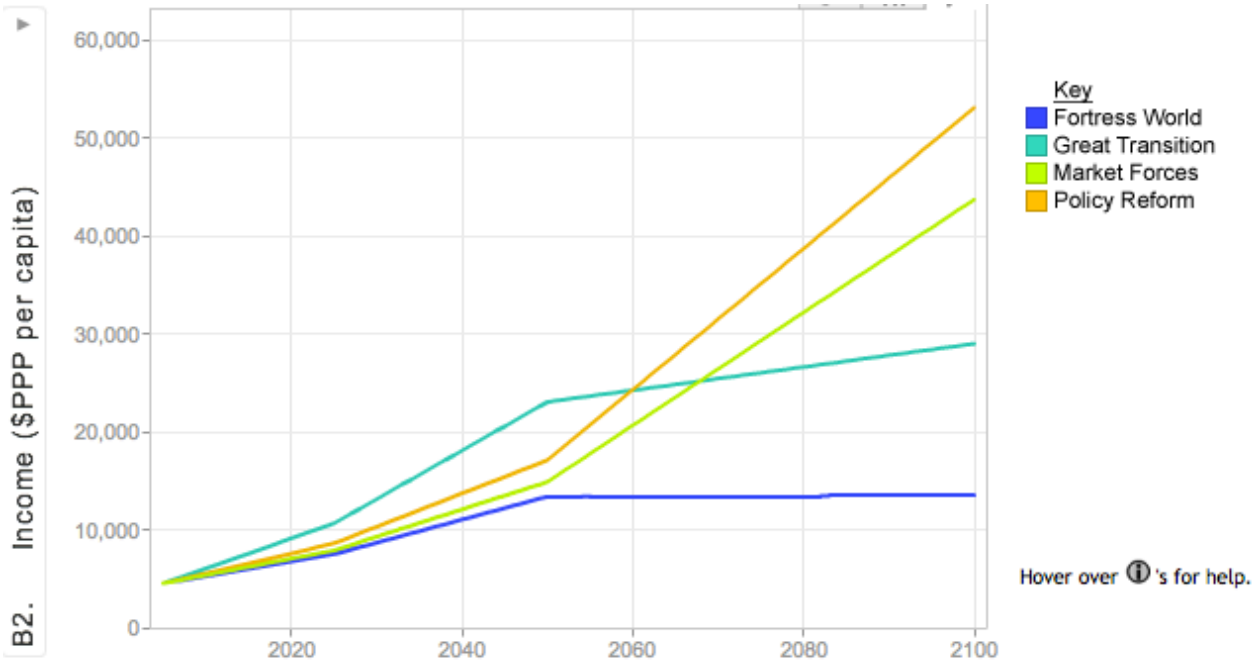
Integrated systems modeling, as described above, can be used in a complementary way with scenario planning, allowing an assessment not only of what some plausible futures are, but how one might make the transition from here to preferred futures.

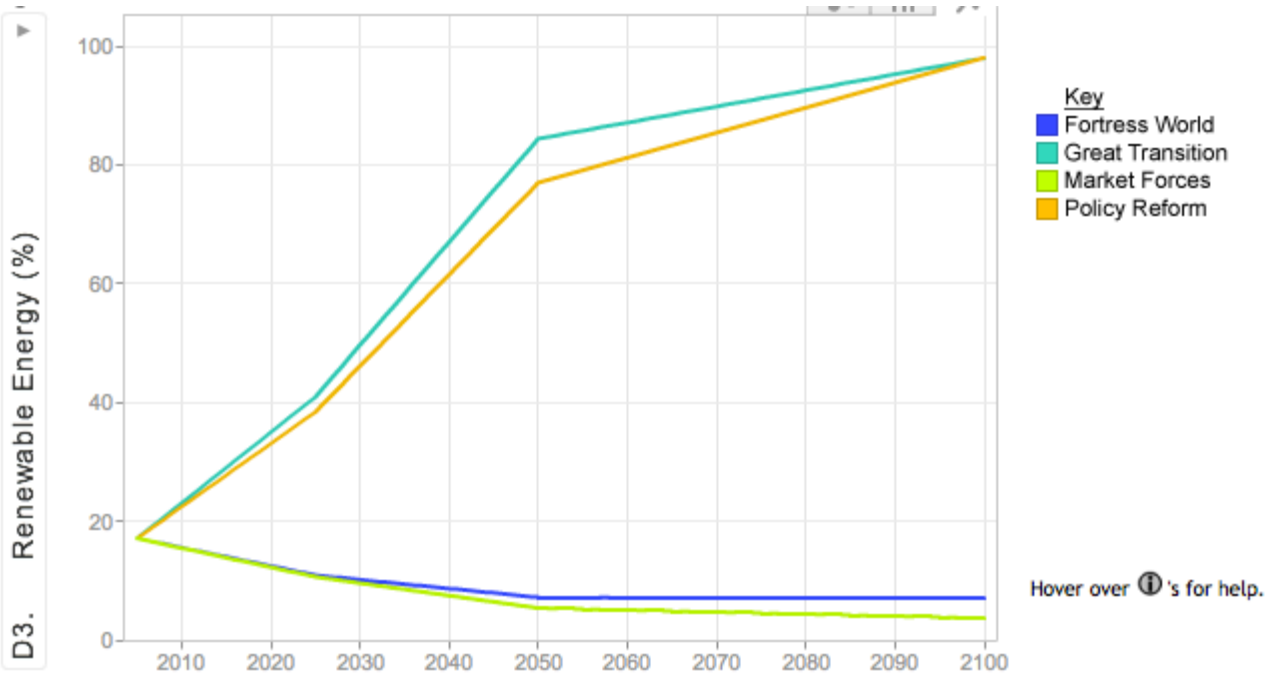
As previously noted, the uncertainties involved in evaluating plans for future development of the LMB are huge, and alternative methods like those discussed above would contribute much to the ongoing assessment.

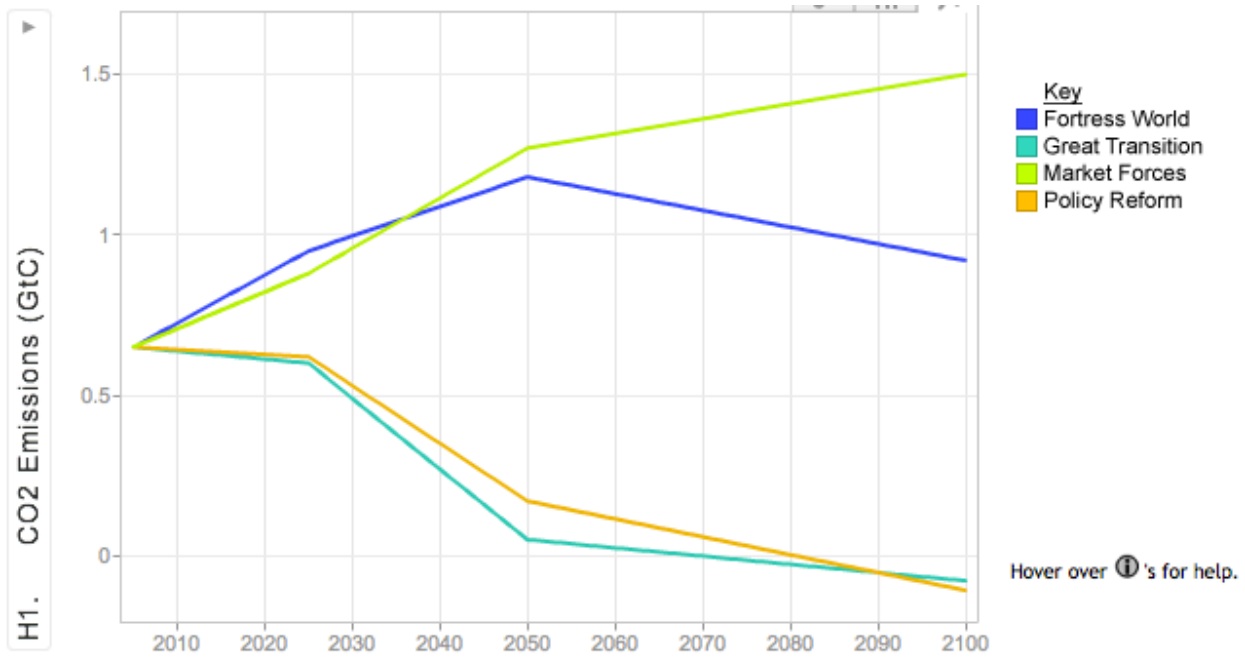
Figure 4.1. Selected indicators for the four GTI scenarios for Southeast Asia (http://gtinitiative.org/)

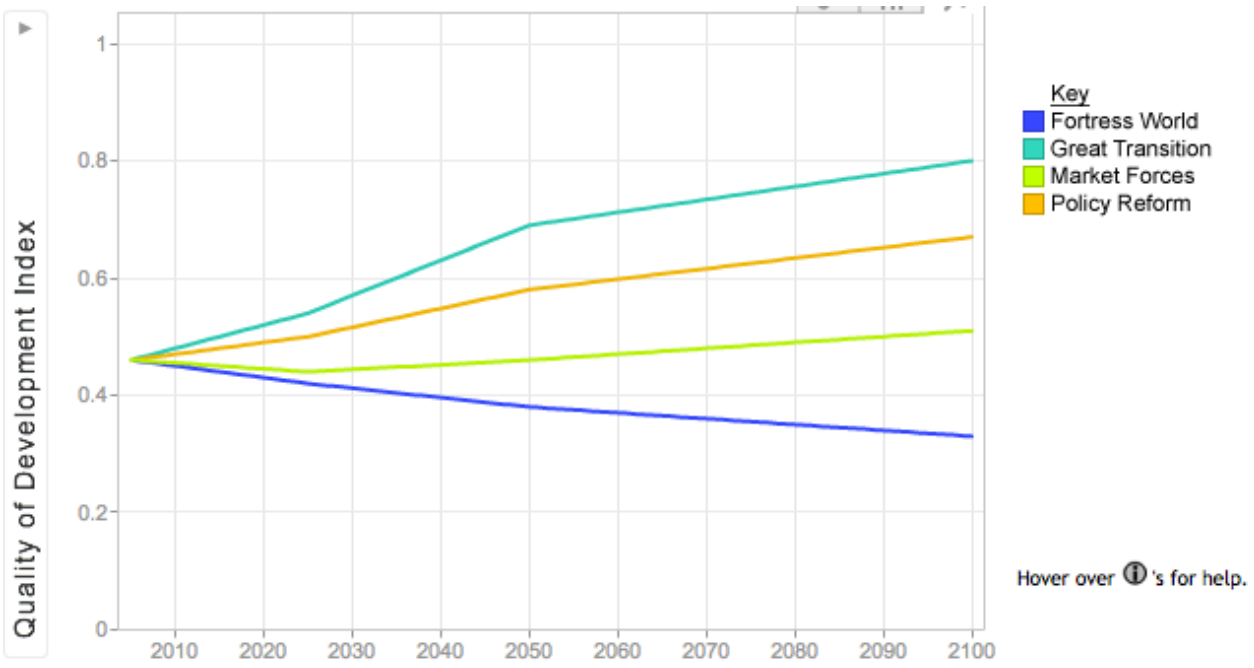



B1. Total GDP (10^9 $PPP)
30,000
25,000
20,000
15,000
10,000
5,000
0
2020
2040
2060
2080
2100
Key
Fortress World
Great Transition
Market Forces
Policy Reform
Hover over ⓘ's for help.


B2. Income ($PPP per capita)
60,000
50,000
40,000
30,000
20,000
10,000
0
2020
2040
2060
2080
2100
Key
Fortress World
Great Transition
Market Forces
Policy Reform
Hover over ⓘ's for help.


D3. Renewable Energy (%)
100
80
60
40
20
0
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Key
Fortress World
Great Transition
Market Forces
Policy Reform
Hover over ⓘ's for help.


H1. CO2 Emissions (GtC)
1.5
1
0.5
0
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Key
Fortress World
Great Transition
Market Forces
Policy Reform
Hover over ⓘ's for help.



4.3. Future Data and Modeling Requirements

Applying the above techniques will require the assembly and collection of additional data, the use of a broader spectrum of models and scenarios, and broader participation in the process at all stages. The analysis, models, and scenarios employed should determine which data are needed.

While integrated modeling requires and incorporates a broad range of types and quality of data, the data available in the LMB should be sufficient to begin to implement these approaches. Methods to display the uncertainty and sensitivity of these models should also be employed to make clear the degree of fit with existing data and the limits on the quality of the data employed. Mediated modeling and scenario planning can be undertaken with existing data and can incorporate the diverse knowledge of participating stakeholders.

Undertaking these new approaches can be seen as an evolving and continuing improvement (adaptive management) in the methods used to evaluate development choices in complex systems like the LMB.

5. Conclusions and Recommendations

BDP scenarios are formulated to evaluate LMB countries' water resources development policies and plans against agreed economic, environmental, and social objectives and criteria. The results, together with other basin-wide assessments (e.g. the SEA of the proposed LMB mainstream dams), provided a basis for discussion and negotiation of mutually beneficial levels of water resources development and their associated levels of transboundary environmental and social impacts. This led to a shared understanding of what could be considered as

development opportunities, as described in the IWRM-based Basin Development Strategy. This report reviews progress to date on the BDP process and makes recommendations about options for additional analytical tools going forward in preparation for the upcoming 2011 Basin Action Plans and the future BDP activities scheduled for 2015. It draws on examples from existing LMB planning documents to illustrate the benefits of these additional approaches.

The development and management of the LMB involves complex problems that are both poorly understood in scientific terms and subject to rapid—sometimes catastrophic—change, over time. A whole systems approach that adequately addresses the risks and uncertainties involved is often a daunting challenge for decision makers and managers. They must develop the capacity to plan, coordinate, and implement a program that improves sustainable societal well-being in the face of these uncertainties, including the management and protection of native capture fisheries, biodiversity, wetlands and other biological resources, ecosystem services, and indigenous cultures and ways of life.

Knowledge of ecosystems and human systems is incomplete; these systems are dynamic, and difficult-to-predict changes can occur over time. Management efforts in the LMB should recognize the dynamic character, complexity, and interconnectedness of linked ecological and human systems. Resource management should move beyond traditional linear thinking and decision making to more of an adaptive management approach that can view policies as experiments from which we can learn (Holling 1978; Walters 1986; Lee 1993; Gunderson et al. 1995). This also implies an expanded level of collaboration and coordination among all the stakeholder groups affected by the BDP.

The following recommendations are intended for consideration in the next phase of the BDP:

- **Implement a more comprehensive, integrated systems framework and adaptive management approach** to LMB planning and development. This should include more sophisticated modeling of the natural, human, and built components of the system and indirect and cross-sectoral effects. For example, the behavior of capture fisheries will depend on a number of factors that interact in complex ways. Better scientific understanding of the behavior of the array of tropical fish in response to dams, reservoirs, various designs of fish passages, etc. is part of it, but this needs to be better integrated with aquaculture potential, real wealth distribution, flood protection, societal and cultural well-being, and a host of other factors. Models that go well beyond the partial equilibrium framework employed in BDP2 to a more comprehensive, dynamic framework that includes built, human, natural, and social capital is needed.

- **Implement a more comprehensive analysis and treatment of risk and uncertainty.** There are multiple sources of risk and uncertainty in the LMB and various methods to deal with them. Some of these were used in BDP2, but they need to be expanded and other methods added. This report explored a broader sensitivity analysis to deal with parameter uncertainty around discounting, the value of fish, and the value of wetlands, but model uncertainty and data quality are probably even larger sources of uncertainty and these were barely touched. Within this sensitivity analysis, the NPV of the various scenarios could range from very positive ($33 billion) to very negative (-$274 billion). Ultimately, the range of uncertainty around these issues needs to be better taken

into account in the next phase and institutions that can deal with this uncertainty employed. For example, hydropower developers could quantify the sediment load passing the dam site annually before the project, establish a post project monitoring mechanism, and have an assurance bond pay out if targets are not met annually. They would have the option, of course, to develop sediment bypass mechanisms to meet the targets. For migrating fisheries, a similar performance bond could be established. In addition, the dam developer should be required to take out catastrophic risk insurance against the failure of the dam from all causes (flood, earthquake, landslide, poor construction, mechanical failure, etc.) This will internalize the risk of failure into the cost of the dam (Costanza and Perrings 1990).

- Table 5.1 is one way to summarize the major uncertainties involved in LMB planning. It shows, on the left, two major policy positions, one optimistic about parameters and models, the other, precautionary. On the top are two alternatives about the real state of the world, again, optimistic and precautionary. The problem is that we do not know the real state of the world and will not know it until after the fact. All quadrants except the second one are net positive by varying degrees. From an adaptive management perspective, given the significant uncertainty about the real state of the world, one should pursue the precautionary policies in order to avoid negative net benefits, at least until the uncertainty can be removed or reduced to an acceptable level.

- Given this fundamental uncertainty, each policy should be examined to find the worst-case outcome. We should then choose the policy with the best worst case. In Table 5.1, if the optimistic policy option is chosen, the worst case is negative net benefits. If the precautionary policy options are pursued, the worst case is slowed economic growth, which is better than negative net benefits. Therefore it is better to adopt the more precautionary policies, at least until the uncertainty can be resolved.

- **Implement a more elaborate treatment of distribution issues**, both among current stakeholder groups and with future generations. The distribution of benefits and costs from dam construction is highly skewed. The poor will bear most of the costs and see few of the benefits, except through trickle down economic growth. The MRC acknowledge that addressing this issue is a high priority. Further work is needed to determine in more detail the distribution of benefits and costs between different groups (e.g., private developers, governments, local communities, fishing households, farming households, consumers, etc.) as well as the impact on poverty within LMB countries. Also there is mounting evidence that a skewed income distribution is highly correlated with a range of social problems and reduced quality of life for both the rich and the poor (Wilkinson and Pickett 2009). How the future is discounted is a key issue in any analysis of projects with long time horizons. Ideas about discounting are rapidly evolving and changing, but there is growing agreement that simply discounting everything at the same, constant exponential rate is too simplistic. Some alternatives to standard discounting were explored and a sensitivity analysis showed that varying the discount rate can have dramatic effects on the estimated net social benefits. Even in our worst-case scenario in the sensitivity analysis, however, the benefits of hydropower are still positive for Lao PDR, while they may be negative for other countries. One approach that might be tried is to implement a form of payment for ecosystem services to Lao PDR (from the other countries in the LMB as well

as elsewhere) larger than the foregone benefits from dam construction. A similar approach has been proposed by Ecuador in return for leaving major Amazonian oil reserves in the ground and in Indonesia for protection of native forests.

- **Develop a more thorough assessment of the value of direct and indirect ecosystem services.** This includes the full range of services from provisioning services like capture fisheries to the broad range of regulatory and cultural services provided by wetlands and other natural ecosystems. Our analysis showed that varying the assumptions about the value of capture fisheries and wetlands can make a significant difference in the evaluation of the net benefits of future scenarios, even changing the sign in many cases. Ecosystem services are becoming an important way of understanding, valuing, and managing our environmental assets, and a more direct and concerted effort to understand, model, and value ecosystem services should be a major part of the next BDP phase. This could include a review, survey, and classification of aquatic habitats in terms of biodiversity and ecological importance; prioritization of key tributaries for ecosystem integrity and health of the Mekong, highlighting those affected by proposed mainstream dams; assessment of the ecological importance and productivity of the seasonally exposed in-channel wetlands; and assessment of the possibilities for river-based ecotourism. In addition, impacts of developments on indirect ecosystem services of the Mekong—both negative (e.g., loss of provisioning, regulating, and cultural services of the river) and positive (e.g., the multiplier effect of hydropower benefits)—should be assessed. Such analyses could also be folded into the integrated modeling mentioned above to model the connections between ecosystem functions and processes and the benefits to various human populations.

- **Consider a broader set of scenarios**. The range of scenarios in BDP2 is fairly narrow, and assumes a "business as usual" context. The MRC acknowledges in the IWRM-based Strategy the importance of moving in the next planning cycle to employ more comprehensive dynamic models and considering a broader set of scenarios that more fully incorporate stakeholder input to address these issues The idea of scenario planning could be more fully employed to develop a much broader range of scenarios that embody alternative models and tradeoffs among conventional economic development, ecosystem services, and cultural issues. This would allow a broader discussion of the choices facing the LMB countries and their populations and allow a more informed choice among the complex tradeoffs involved.

Table 5.1: Alternative policy assumptions vs. future state of the world for LMB development choices.

Policy Choices	Future State: If optimistic assumptions correct 1. lost capture fisheries and related livelihoods and cultures can be replaced (e.g., with aquaculture) 2. 10% discount rate is appropriate for all capital (including natural) 3. distribution and cultural issues are not extremely important 4. no viable energy alternative to large hydropower 5. other risks are negligible	Future State: If precautionary assumptions correct 1. lost capture fisheries very important to local populations and not fully replaceable with aquaculture. 2. 1% discount rate for natural capital (10% for aquaculture) 3. distribution and cultural issues very important 4. small scale hydro, wind, and solar energy are viable energy options 5. other risks [e.g., earthquakes] are significant
Optimistic Rapid economic growth is the primary mode of increasing well-being via hydropower, water supply, irrigation, and flood protection.	**1. Optimistic future** includes: positive net benefits and rapid economic growth outweighing negative social and environmental outcomes.	**2. Negative net benefits** include: large decrease in well-being of local populations, risk of catastrophic losses, and permanent damage to the environment.
Precautionary More broadly defined sustainable human well-being is the primary goal. Construction should pause until uncertainty is resolved. The SEA precautionary approach includes the evaluation of a broader range of alternatives and the requirement of assurance bonds.	**3. Economic growth is slowed** and delayed, but local populations and fisheries are maintained. The burden of proof shifts to dam developers.	**4. Long-term human well-being is enhanced,** even though conventional economic growth slows.

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Appendix A:
Potential Alternatives for Power Production

Introduction

The scope of BDP2 was to assess the LMB countries' own hydroelectric expansion plans (HEP) and not to validate their optimality or examine alternatives to those plans. However, the IWRM-based Basin Development Strategy recognizes the need to investigate power generation issues and a study is planned by the MRC of mainstream and tributary hydropower potential and alternative power options, including innovative hydropower schemes that do not affect connectivity in the LMB. In this connection, this appendix presents a preliminary review of alternatives to mainstream dams to serve the power needs of LMB countries. The alternatives presented in this appendix are potential opportunities for energy production within the LMB at various scales. The purpose of assessing these opportunities is to understand the stage and commercial readiness of different technologies, and their potential applicability or nonapplicability to the Mekong, in order to inform a discussion on which resources might be further researched and developed in lieu of mainstream hydropower if development of mainstream dams is deferred or curtailed. Investigations into these alternative energy developments are also needed if more comprehensive planning scenarios are to be developed for future assessment exercises in the LMB.

This appendix does not answer the question of how the LMB countries could meet their energy security goals or, for example, how Lao PDR could meet its 2020 poverty reduction goals without the budget injections from the mainstream dams. The purpose of this appendix is to present only a review of different technologies and offer preliminary comparisons of estimated costs of power generation for discussion purposes. Understanding their full applicability to the LMB, and, specifically, their relative scale of potential power generation to the mainstream and tributary hydropower projects, requires investigation of site specific data and is therefore a subject of further studies.

The appendix is divided into four sections. Section one describes hydropower and related power generation technologies. An extensive discussion of in-stream hydrokinetic generation is provided in this section. In section two, comparisons are drawn between benchmark fossil fuel resources, proposed mainstream hydropower projects, other hydropower and hydrokinetic resources, and other renewable resources. Section three provides observations regarding electricity resource planning and recommendations for research and development on promising resources. Section four provides additional information on non-water-based renewable generating options.

1. Hydropower and Related Generating Resources

Hydropower and related generating resources include large-scale impoundments, diversion projects, ocean wave generation, river current hydrokinetic generation, ocean thermal energy conversion (OTEC), salinity gradient generation, and tidal current hydrokinetic generation.

Conventional hydropower is classified by generating capacity, regulating capability (storage, run-of-river, or run-of-release), and water head. The classification of conventional hydropower chosen for this assessment is large-scale storage or run-of-river impoundments, run-of-river diversion or bypass projects, and addition of run-of-release power generation to existing nonpower impoundments and conduits.

Large-Scale Storage and Run-of-River Hydropower Impoundments

Large-scale impoundments with power generation typically consist of a dam with spillway and integral powerhouse, switchyard and transmission interconnection. Projects may also include upstream and downstream fish passage facilities, sediment flushing sluices and navigational locks. Impoundment projects provide firm capacity, energy and load following. Where topography permits, projects are often designed with working storage to provide seasonal regulation. Alternatively, projects may have little working storage and provide run-of-river output. As typical for river basin development, the upper Mekong (Yunnan) mainstream projects have substantial storage and regulation capability whereas the proposed lower mainstream projects would operate primarily as run-of-river facilities. Eleven of the twelve proposed lower Mekong mainstream projects are large-scale run-of-river impoundments. The twelfth project, Thakho, is a diversion type, discussed in the following section. The capacity, average energy production, total project cost and estimated levelized cost of electricity over the economic life of the lower mainstream impoundment projects are shown in Table A1. Here and in the sections that follow, common financing assumptions[6] are used to provide comparable estimates of energy costs.

Table A1: Capacity, average energy production, total project cost, and estimated levelized cost of electricity over the economic life of the lower mainstream impoundment projects

Project	Capacity (MW)	Average Energy (GWh/yr)	Total Plant Cost[7] ($/kW)	Levelized Energy Cost ($/MWh)
Pak Beng	1230	5268	$1633	$45
Luang Prabang	1410	5437	$1679	$51
Xayaburi	1260	6035	$1554	$38
Pak Lay	1320	5421	$1546	$44
Sanakham	1200	5015	$1490	$42
Sangthong-Pakchom	1079	5318	$2068	$49
Ban Koum	1872	8434	$1998	$52
Latsua	686	2668	$2619	$60
Don Sahong	360	2375	$2026	$36
Stung Treng	980	4870	$4984	$117

[6] Cost estimating assumptions: 2009 year US dollar values, 2015 service, 30-year economic life, 8 percent cost-of-capital and discount rate, no taxes, royalty payments, or financial incentives. Though the assumption of no taxes, royalty payments, or financial incentives is clearly not representative of real-world development, the purpose of these estimates is to provide a common basis of comparison among resources.

[7] The project costs provided in MRC (2009) are described as "Project Investment (PV at Start)." This value is interpreted as Total Plant Cost (i.e., exclusive of financing costs and escalation and interest during construction) in constant 2009 dollars. In calculating levelized energy cost we assume that the investment costs include project development, infrastructure, and other owner's costs; if not, the actual costs will be 15 to 20 percent higher than shown here.

Sambor	3300	14870	$2241	$58

Source: author's calculation based on capacity, energy, and investment cost from MRC (2009)

Diversion Hydropower Projects

A diversion hydropower project diverts a portion of stream flow from an upstream location to a downstream, lower elevation powerhouse. Because the energy available to a conventional hydropower turbine is directly proportional to the water head (pressure) and volume, the relatively high head of diversion projects allows the generation of electricity with proportionally smaller water volume than lower heads typical of most dams with integral powerhouses. A portion of the natural flow sufficient to support the natural ecology and aesthetics is maintained in the bypassed channel. A diversion project typically consists of a small headwater pond created by a low diversion dam or weir, an intake structure, a penstock[8] leading to a powerhouse at lower elevation and a tailrace to convey water from the discharge of the turbines back to the stream. The head is developed in the penstock as it drops from the intake elevation to the powerhouse elevation. Depending upon topography, diversion projects may include a lateral canal or low-pressure conduit to convey flow from the diversion to a point above the powerhouse to minimize the run of the more expensive high-pressure penstock. Because diversion structures are generally low and headwater ponds small, diversion hydroelectric projects avoid many of the environmental impacts of impoundment projects, providing that sufficient flow is maintained in the bypassed reach to support the native habitats.

Most diversion projects have little or no storage capability and operate on "run-of-river" flow. They provide firm capacity, energy, and some load-following capability. Run-of-river diversion projects range in capacity from tens of kilowatts to hundreds of megawatts. Larger projects justify longer transmission interconnections, and normally interconnected to a main grid. The transmission interconnections from larger headwater diversion projects can provide grid interconnection to intermediate off-grid loads. Small diversion projects can be dedicated to off-grid loads.

Most diversion projects are located in headwater drainages where stream gradients tend to be steep. This minimizes the length of the water conveyance structures but may limit the volume of water available for diversion. Waterfalls or cascades on lower reaches offer opportunities for close-coupled, high volume diversion projects. The proposed 50-megawatt Thakho Diversion project on the mainstream Mekong at Khone Phapheng Falls is of this type. Like headwater diversion projects, extensive alternation of the natural channel is not required. Because a natural drop often represents a natural barrier to the migration of aquatic fauna, environmental impacts can be minor. In-stream flows at major falls are often maintained for aesthetic purposes.

The cost of diversion projects is site-specific and varies greatly because of the range of sizes, diversity of project configurations, and the significant effect of factors such as terrain and length of transmission interconnection. Cost and energy production information was obtained for 35 recently developed or proposed North American projects ranging from 1.2 to 335 megawatts. The levelized energy cost of these projects, calculated using the common financing assumptions

[8] The pressurized pipe that conveys water to a hydropower turbine.

of this assessment ranges from $36 to $283/MWh. The energy-weighted cost is $96/MWh. The cost of comparable projects in the lower Mekong basin is likely to be lower because of lower labor costs. Using the same financial assumptions, the levelized lifecycle energy cost of the proposed 50 MW Thakho diversion is $35/MWh—the least cost of the proposed mainstream projects.

The regional potential for diversion project development is not known. The project database referred to in the BDP2 Hydropower Review (MRC 2009) may provide sufficient information for an initial estimate of undeveloped diversion project energy potential. This database, however, was not made available for this study.

Retrofit of Hydropower Generation to Existing Water-Control Structures

Opportunities exist to add power generation equipment to existing storage dams constructed for irrigation, flood control, or other nonhydropower purposes. Equipping these facilities to produce power is usually accomplished by modification of the existing discharge works, and addition of a powerhouse, tailrace, and switchyard and transmission interconnection. The incremental cost and environmental impact is therefore much less than that of a new dam and storage reservoir with power generation. The powerhouse generally operates in "run-of-release" mode, since power generation typically remains subordinate to original purpose of the facility. For example, releases from an irrigation facility may be limited during the wet season as water is stored for dry season releases.

Like other hydropower projects, the cost of power retrofits is site-specific and varies due to capacity, project configuration, length of transmission interconnection, and water release hydrograph. Cost and energy production information was obtained for nine recently developed or proposed North American projects ranging from 2.6 to 15 megawatts. The levelized energy cost of these projects, calculated using the common financing assumptions of this assessment ranges from $59 to $156/MWh.

Irrigation canal drops, irrigation wasteways, and municipal water supply system pressure reduction valves can also provide opportunities for addition of power generation capacity (conduit projects). Canal drop and wasteway projects generally involve diverting the full flow into a penstock that leads to a powerhouse at lower elevation. After passing through a turbine, the water is returned to the canal (or receiving stream in the case of a wasteway). Small hydropower turbines can be substituted for pressure reduction throttle valves in municipal water systems. Power production of conduit projects is run-of-release.

Like other hydropower projects, the cost of conduit power retrofits is site-specific and varies due to capacity, project configuration, length of transmission interconnection, and water release hydrograph. Cost and energy production information was obtained for five recently developed or proposed North American projects ranging from 750 kilowatts to 10 megawatts. The levelized energy cost of these projects, calculated using the common financing assumptions of this assessment ranges from $48 to $600/MWh. The high cost of several of these projects is partly attributable to the cost of long runs of large-diameter penstock runs over low gradient canal sections for the nonpower purpose of reducing water loss from unlined canal.

The energy-weighted cost of the 14 power retrofit projects discussed above is $90/MWh.

No inventory of nonpower dams or conduit hydropower development opportunities in the Lower Mekong Basin was located for this assessment. An assessment of the power potential of these facilities would commence with an inventory of existing nonpower projects, annual release hydrograph, reservoir operating rule curves, existing discharge works, and transportation and transmission infrastructure.

River Current Hydrokinetic Generation

Hydrokinetic energy conversion devices convert the kinetic energy of flowing water to electric power. Hydrokinetic devices for shallow channel applications show promise for small-scale power production from shallow streams, canals, tailraces, and outfalls. (Deepwater hydrokinetic technology suitable for capturing the energy of tidal and oceanic currents and the flow of deep (> 10 m) river channels are discussed later). Because of the kinetic energy density of flowing water, commonly encountered velocities are low and hydrokinetic devices have lower inherent conversion efficiency than conventional hydropower turbines. Hence, the capacity of river-current hydrokinetic installations will be small, ranging from tens of kilowatts to several megawatts. These facilities will be best suited to serving isolated and community-scale loads where they will compete with diesel generators, small hydropower diversions, community-scale wind, solar photovoltaic arrays, and small biofuel power plants. In-stream hydrokinetic plants will be able to produce power year-round in most locations. However, strongly seasonal streams will require backup diesel or biofuel capacity for use during the low-flow season.

In-stream hydrokinetic units can be deployed at sites lacking suitable topography for conventional hydropower. The physically compact and modular nature of hydrokinetic devices will facilitate transportation to remote areas and installation can be accomplished in many cases without the need for major civil works and heavy construction equipment. The compact and modular nature of the technology may facilitate rapid technical development and economies of production. Relatively conventional materials and technology are employed in the fabrication of hydrokinetic energy conversion units, facilitating the establishment of domestic manufacturing capability.

In-stream hydrokinetic devices do not block or alter natural channel geometry, or greatly affect flow velocity. Estimates of the impact of hydrokinetic flows for several sites in Alaska suggest reductions in flow velocity immediately downstream of hydrokinetic device arrays of 7 percent, or less (Previsic 2008). Thus, broad environmental impacts are expected to be far less than for conventional hydroelectric projects, except in cases where a large number of units have to be installed to maximize power output resulting in an increased environmental footprint. Moderate local impacts are also possible, including alteration of habitat, erosion and scouring, hydraulic shear stresses, turbulence, strike, entanglement, impingement, electromagnetic field effects, toxic materials, noise, and vibration. Because of the lack of large civil works, in-stream hydrokinetic facilities can be removed to reverse unanticipated environmental impacts.

A wide variety of design concepts for in-stream hydrokinetic devices have been proposed. Seventy-six of these are reviewed by Khan and others (2009). The fundamental design consideration is the energy capture mechanism; concepts include turbines, oscillating surfaces, piezoelectric, and induced vibration. Turbine-based concepts include axial, crosscurrent, and vertical axis rotors. Both drag (paddle) and lift (foil) turbine blades have been proposed. Other unsettled design parameters include support (gravity-founded or floating), submerged versus nonsubmerged generators, debris protection, fish screening, and the use of ducting to augment energy capture efficiency.

Turbine-based concepts are at the forefront of development. Lift blading is more efficient than paddles, though paddles may be less susceptible to weed and line entanglement. Floating arrangements position turbines near to the surface where flow velocities are the greatest, and automatically correct for changes in water level. Floating devices can be configured with nonsubmerged generators, and can be easily repositioned or moved to shore for maintenance. However, floating structures may interfere with navigation and may be more susceptible to damage or entanglement by floating debris.

Optimal turbine configuration is less settled. Vertical axis turbines offer advantages of design simplicity, easier generator coupling, nonsubmerged generator positioning, potential use of rectangular or curvilinear ducts with integrated flotation, lower noise, and less sensitivity to shear flow. Vertical axis turbines, though, are less efficient than axial flow machines, may produce torque ripple, and may not be self-starting. Axial-flow turbines are self-starting, produce little torque ripple, and benefit from an abundant knowledge base. Axial flow machines operate at a higher rotational speed, thereby reducing gearbox complexity. Higher turbine rotational speeds, however, may increase strike hazard and require screening. Axial flow turbines can be equipped with annular ducts that provide greater flow augmentation than the rectangular or curvilinear ducts used for vertical axis machines.

Johnson and Pride (2010) characterize river current turbines as an emerging technology, similar to wind 15 to 20 years ago. This would appear optimistic. Fifteen to 20 years ago, thousands of commercial wind turbines were operating and deployment of second-generation commercial technology was underway. River current turbines presently exist only as a scattering of prototypes and a plethora of conceptual designs. Though several firms have marketed small-scale in-stream turbines, no thoroughly tested commercial product appears to exist, and no commercial-scale installation has been deployed.

Achieving widespread commercial deployment of in-stream hydrokinetic technology will require refinement and commercial production of units optimized to representative sites, greater understanding and resolution of environmental issues, site surveys and evaluation, establishment of performance, permitting and manufacturing standards, and understanding and resolution of operating and maintenance issues. EPRI (2008) estimates the time from conceptualization to deployment of a full-scale river current hydrokinetic prototype to be about five years. A full year of operation, at minimum, is required for testing and evaluation. Another five years may be required for design and testing of a commercial machine. With consistent support, a new concept will require 10 to 11 years from conceptualization to reliable commercial product. This period could be shortened by several years for designs adapted from current prototypes. Once

developed, commercial deployment can be rapid, as fabrication and installation of an array can be accomplished within a year.

One set of cost estimates for a representative design was located for this review. The Electric Power Research Institute has conducted a system-level feasibility study of in-stream hydrokinetic installations at three Alaskan villages (Previsic 2008). The villages of Igiugig and Eagle are served by isolated microgrids using diesel generators. The third community, Whitestone, has been served by an isolated microgrid, but will be connecting to a main grid. The Iguigig and Whitestone cases are most representative of a humid warm climate site in that they are located on streams that flow year around, while Eagle is located on the Yukon River at a location fully clear of ice only five months a year. Two plant sizes were evaluated for Iguigig, a 3-unit 41kW array sized for load at maximum flow and a 9-unit 123kW array sized for load at minimum flow and provided with resistive load banks for dumping excess energy. Two cases were also considered for Whitestone, a 4-unit 79 kW array sized for local load and a 30-unit 594 kW array sized for selling excess energy when the main grid connection is established.

The assessment was based on a conceptual design consisting of a pontoon structure supporting four submerged generators, each powered by a fixed blade open rotor axial-flow turbine with debris and fish screens. A version using 1.5 m diameter rotors and would be rated at 14 kW. A second version using 2 m diameter rotors would be rated at 20 kW. These conceptual designs appear to be applicable to LMB sites.

The cost estimates were normalized to 2009 dollar values. An allowance for preconstruction project development, infrastructure, and other owner's costs were added. Levelized revenue requirements and unit energy costs were calculated assuming a 15-year economic life. The financing assumptions described earlier yield levelized energy costs of $274 to $477/MWh. While competitive with diesel generator sets, these costs are far higher than other sources available to the main grid.

A favorable site will be adjacent to a microgrid to minimize voltage drop and electrical losses and have current velocity of at least 1, and preferably 1.5 m/s. Excessive velocities (exceeding 3.5 m/s) may be characterized by high sediment load and unstable channels leading to equipment wear and to anchoring and servicing difficulties. A good site will need sufficient midstream depth to accommodate the hydrokinetic energy conversion device and be of sufficient area to accommodate the needed number of units. Freedom from floating debris and relatively constant seasonal flow are other desirable attributes.

A complete site assessment will require a flow velocity frequency distribution and seasonal variation, channel geometry mapping, vertical and horizontal velocity profiles, and information regarding channel bed composition and debris and sediment loading. Annual load duration curves and seasonal variation for the local grid, an inventory of existing generation, options for meeting forecast load growth, and location and voltage of possible points of interconnection are needed. River usage and environmental information will be required; these needs can be refined as pilot projects are deployed representative sites and understanding of machine/environment interactions improves.

Little published information regarding current velocities in the LMB were located. Sokleang (undated) estimates average wet season Mekong mainstream current velocity between Pakse, Laos, and Kratie, Cambodia, to be 1.9 m/s, well above the 1 m/s considered feasible for hydrokinetic generation. Current velocities will vary along this reach, but this estimate suggests adequate velocity is available in some reaches, at least during the high runoff season. In contrast, water quality reports for a 22 km reach at the site of the proposed Xayaburi hydropower project cite current velocities of 0.25 to 0.5 m/s in November and 0.4 to 0.6 m/s in March (TEAM 2010). These velocities are well below those suitable for hydrokinetic generation. Flow estimates and documentation of channel geometry and environmental conditions may be available for other sites considered for conventional hydropower development. In addition, the Rivers System Research Group of the University of Washington appears to be developing flow estimates for the Mekong using hydrologic models and remote sensing (http://www.cev.washington.edu/story/VMB). Others working on site assessment methods include the Canadian Hydraulics Center, the University of Alaska, Anchorage, and the U.S. Department of Energy.

Additional mainstream hydrokinetic potential using deepwater technology may be present in the Mekong Delta.

Ocean Wave Generation

Increased interest in wave energy in recent years is resulting in accelerated development of wave energy conversion devices, assessment of environmental and socioeconomic effects and refinement of assessments of wave energy potential. A variety of wave energy conversion concepts are in various stages of development ranging from conceptualization to precommercial demonstration. However, the wave energy potential of the South China Sea is not promising. A recent assessment of global wave energy found that the annual average wave power potential of the Viet Nam coast is of low quality, ranging from five to 15 watts per meter (Mørk et al. 2010). For comparison, the wave power of coastlines considered promising for the commercial deployment of wave energy conversion devices ranges from 40 to 60 watts per meter, and greater. Moreover, the wave power of the South China Sea exhibits a very high degree of seasonal variation. The wave power potential of the Gulf of Thailand is less than five watts per meter.

Salinity Gradient Generation

Energy is released when fresh and saline water are mixed. The energy potential created by fresh water streams discharging to salt water bodies conceptually can be recovered and converted to electricity. Conceptual salinity gradient conversion technologies include osmotic hydro turbines, dilytic batteries, vapor pressure turbines, and polymeric salinity gradient engines. Osmotic hydro turbine technology is the furthest advanced. The Norwegian utility Statkraft has completed a 4-megawatt prototype osmotic hydro turbine power plant near Oslo with the intention of developing a commercial-scale plant by 2015 (http://www.power-technology.com/projects/statkraft-osmotic/). A key to commercialization is reducing the cost of the osmotic membrane. Because of the volume of flow, the theoretical resource potential at

the estuary of the Mekong may be substantial. However, saline intrusion would constrain the ability to tap this resource.

Ocean and Tidal Current Generation

Hydrokinetic devices can be used to capture the energy of oceanic and tidal currents. The leading conversion technologies for these applications are bottom-founded, fully submerged open axial flow turbines, resembling stubby-bladed wind machines. Turbines are mounted on pedestals or in groups of several turbines on gravity-founded racks. The turbines are provided with reversible blades or yawing capability to capture both ebb and flood tidal currents. Tidal currents of sufficient magnitude for the practical production of electric power are typically located in well-defined locations and tidal current power plants are conceived as arrays of individual units at productive sites.[9]

The output of tidal current turbines is cyclically variable. In locations with semidiurnal tides such as the South China Sea, energy production will peak four times a day on the two flood and the two ebb tides. In contrast to other variable output renewable technologies such as wind and solar, the timing and magnitude of tidal cycles and the output of tidal energy conversion devices can be forecast years in advance.

Tidal hydrokinetic conversion technology is approaching the commercial pilot stage. Firms planning commercial installations include Verdant Power and Marine Current Turbines. Verdant Power's "Free Flow" Kinetic Hydropower System is a fully submerged five-meter diameter, three-blade open turbine rated at 35 kW (http://verdantpower.com). Commercial machines will be mounted in groups of three on a gravity-founded "tri-frame." Prototype testing commenced in 2002 and was followed in 2006–2008 by installation of six full-scale demonstration units in New York's East River. In December 2010, Verdant applied to the U.S. Federal Energy Regulatory Commission (FERC) for a license to install a one-megawatt pilot project consisting of 30 turbines on ten frames at the East River site. Verdant commenced a second demonstration project in the St. Lawrence River in 2007, and plans to commence commercial build-out in 2011. The design low water depth of the commercial Free Flow unit is 10 meters, allowing the units to be installed in deeper stream channels.

The Marine Current Turbines "Sea-Gen" conversion technology consists of two 16-meter two-blade open turbines mounted on pivots at the ends of a horizontal beam (http://www.marineturbines.com). Each turbine is rated at 600kW at 2.4 m/s current for a total of 1.2 MW per unit. The beam in attached by a lifting mechanism to a monopile pedestal extending above the water surface. This allows the turbines to be raised above water level for maintenance. The Sea-Gen is intended for open marine applications and requires a minimum depth of 24 meters.

[9] An earlier approach to capturing tidal energy is the construction of barrages across the mouth of bays or estuaries with extreme tides. The barrages are provided with inlet gates and reversible turbines to capture energy from the tidal ebb and flow. Several projects of this type are in operation, the largest being the Rance barrage in France. Though additional barrage proposals have surfaced over the years, interest has shifted to submerged hydrokinetic turbines because of the cost and environmental impact of barrage concepts and the limited number of sites with suitable topography and tidal range.

The only published cost and performance information available for marine-type hydrokinetic turbines are estimates released by Marine Current Turbines for proposed pilot projects in the British Isles. Estimated capital costs of $11,000/kW and a capacity factor of 50 percent yield an estimated energy cost of $325/MWh.

Ocean and tidal currents of sufficient velocity to have practical potential for electric energy production may occur at near-shore sites along the southern Viet Nam coast. The October through April Northeast monsoon drift runs along the Viet Nam peninsula, and may attain surface velocities of 1 to 1.5 m/s. This velocity is within the low end of the feasible range of hydrokinetic energy conversion devices. The June to August currents are weaker, attaining velocities of 0.5–1.0 m/s.

Potential for hydrokinetic generation using tidal hydrokinetic conversion systems may also be found in the delta reaches of the Mekong below Phnom Penh. Here, tidal currents influence river flow. Wet season ebb currents to 2 m/s are reported as far inland as Phnom Penh on the Song Tien Giang channel. Dry season ebb currents near the mouth are reported to be about 1 m/s (Prostar 2004). These currents are feasible for hydrokinetic generation, but because of the complex interaction between river flow and tidal effects, further documentation of the time variation and direction of currents are needed to ascertain the feasibility of hydrokinetic power production. Further investigation is also needed to determine if channel depths are sufficient for tidal hydrokinetic devices. MRC flood forecasting channel cross sections suggest that sites with adequate depth (10 meters, or greater) are present (Table A2). The Hydrographic Atlas of the Mekong River (Cambodia and Viet Nam) published by the MRC Data and Information Services (http://portal.mrcmekong.org/) and nautical charts of the lower Mekong may provide useful information for further assessment of resource potential.

Table A2: Center channel depths reported for the southern Mekong

Site	Center Channel Depth (m)
Phnom Penh (Port)	7–10
Phnom Penh (Bassac)	3–15
Koh Khel	2–6
Chau Doc	13–15
Neac Luong	17–20
Tan Chau	20–35

Source: MRC (http://ffw.mrcmekong.org/south.htm)

2. Comparison of Electric Power Resource Alternatives

Assessing the prospects for developing new power generating resources requires an understanding of the cost of competing resources. A basic principal of power system planning is to consider all resources having the potential to provide the needed power system services including demand side, energy storage, and generating resources. In this section, comparisons are drawn between benchmark fossil fuel resources, proposed mainstream hydropower projects, other hydropower and hydrokinetic resources, and other renewable resources.

Reference Fossil Fuel Generating Options

Coal, natural gas, and nuclear resources constitute the principal alternatives to large-scale hydropower for supplying bulk power to large-scale electric power grids. These are the resources against which other bulk power sources should be compared in terms of cost, environmental and social impacts, uncertainty, and risk. One or more of these alternatives are called for in the energy strategies of Cambodia, Thailand, and Viet Nam. While limited coal is produced for the cement industry, Lao PDR at this time does not have domestic fossil fuel resources to support coal or natural gas generation. Other than nuclear units, the development of which would appear to be infeasible at present for a country the size of Lao PDR, hydropower appears to be the principal source of additional domestic bulk power production.

Reciprocating engine-generator sets using distillate or residual fuel oil are the reference resource for community-scale power systems or small isolated power grids. This is the resource against which alternative local sources of electricity should be compared in terms of cost, environmental and social impacts, uncertainty, and risk.

The next two subsections establish normalized levelized cost of electricity estimates for natural gas combined-cycle plants and pulverized coal-fired power plants. These constitute the resource alternatives against which other new sources of bulk power should be evaluated. The third section establishes normalized levelized cost of energy estimates for diesel-fuelled reciprocating engine-generator units. This is the resource alternative against which other new sources of micro grid power should be compared.

Natural gas combined-cycle power generation. The natural gas combined-cycle power plant is the established technology for bulk electricity production from natural gas. Combined-cycle units provide energy, firm capacity, and load-following capability. High reliability and efficiency, low capital cost, relatively low CO_2 production, short lead-time, operating flexibility, and low air emissions have positioned gas-fired combined-cycle plants as the bulk power generation resource of choice in areas with pipeline access to gas. The emergence of the ability to economically produce natural gas from shale formations through horizontal drilling and fracturing techniques has greatly expanded natural gas reserves in North America, and is expected to do so globally. This has relaxed concerns regarding natural gas price risk, further cementing the leading position of gas combined-cycle bulk power technology, especially in regions with direct pipeline access to extensive gas reserves. Development of the extensive gas resources of the South China Sea, though currently contested in terms of national claims, is likely to lead to an expanding role for combined-cycle generating technology in the Lower Mekong region.

Viet Nam and Cambodia have access to South China Sea reserves of natural gas, and the cost of power from a new gas-fired power plant will remain an important consideration in evaluating the cost-competiveness of alternative bulk power generation resources. The levelized cost of electricity from a reference gas combined-cycle power plant is estimated to be about $47/MWh in the BDP2 Hydropower Sector Review (HSR) (MRC 2009). The normalized financing assumptions of this study with an 8 percent discount rate yield $43/MWh for the same underlying assumptions (Case 1 of Table A3). The capital cost used in the BDP2 HSR is consistent with the cost of the recently completed Nhon Trach 2 combined-cycle plant and the

heat rate is consistent with current combined-cycle technology. The assumed capacity factor (60 percent) of BDP2 HSR is lower than the expected capacity factor of Nhon Trach 2 (68 percent). Applying the expected capacity factor of Nhon Trach 2 yields an estimated levelized power cost of $41/MWh (Case 2 of Table A3). The base year natural gas price assumed in BDP2 HSR ($3.50/MMBtu) appears reasonable, but most analysts expect some escalation in natural gas prices in future years because of the clean-burning, low-carbon quality of the fuel. The International Energy Agency estimates a long-term average annual escalation of natural gas of 0.7 percent (IEA 2010). Applying a 0.7 percent annual gas price escalation yields $44/MWh (Case 3 of Table A3). One additional variable should be considered: the potential value of carbon dioxide (CO_2) allowances should international efforts at greenhouse gas control be established. Estimates of the future value/cost of CO_2 allowances abound, ranging from zero to in excess of $100/ton CO_2. The Northwest Power and Conservation Council, drawing upon the advice of experts in the field, adopted a range of estimates yielding a mean value of about $48/ton CO_2 by 2030 (NPWCC 2009). Applying this cost to the reference plant yields a electricity cost of $62/MWh (Case 4 of Table A3). Cases 3 and 4 will be used in subsequent comparisons.

Table A3: Reference natural gas fired combined-cycle plant

Case	Total Plant Cost ($/kW)	Heat Rate (Btu/kWh)	Base Gas Price ($/MMBtu)	Annual Fuel Price Escalation	Capacity Factor	Levelized Energy Cost ($/MWh)
1. BDP2 HSR assumptions, normalized financing	840[10]	7000	$3.50	Zero	60%	$43
2. Case 1 w/ 68% capacity factor	840	7000	$3.50	Zero	68%	$41
3. Case 2 w/ IEA gas price escalation	840	7000	$3.50	0.7%	68%	$44
4. Case 3 w/ CO_2 cost	840	7000	$3.50	0.7%	68%	$62

Coal-fired steam-electric power generation. The pulverized coal-fired power plant is the established technology for bulk electricity production from coal. These plants provide energy and firm capacity and limited load-following capability. Most new coal plants, including the Thai Binh 2 plant in Viet Nam for which construction was announced in March, use supercritical technology. Supercritical steam cycles operate at higher temperature and pressure conditions than sub-critical units. This results in higher thermal efficiency with corresponding reductions in fuel cost, carbon dioxide production, air emissions and water consumption.

[10] MRC 2009 uses an EPC (engineering, procurement, and construction) cost of $700/kW. Total plant cost also includes owner's costs for infrastructure, project development, and construction administration. Typical owner's costs are about 20 percent of EPC costs, yielding the total plant costs shown. Total investment costs include financing fees and interest and escalation incurred during construction and are typically 10–15 percent greater than total plant cost.

Viet Nam has substantial reserves of anthracite-grade, low-sulfur coal, and the cost of power from a new coal-fired power plant will remain an important consideration in evaluating the cost-competiveness of alternative bulk power generation resources. The levelized cost of electricity from a reference coal-fired power plant is estimated to be about $88/MWh in the BDP2 HSR (MRC 2009). The normalized financing assumptions of this study with an 8 percent discount rate yield $80/MWh for the same underlying assumptions (Case 1 of Table A4). The heat rate used in the BDP2 HSR (8000 Btu/kWh) is much lower than the heat rate assumed for supercritical units by the U.S. DOE (9000 Btu/kWh). Applying the latter heat rate yields an estimated power cost of $86/MWh (Case 2 of Table A4). The coal price assumed in BDP2 HSR is $5.51/MMBtu. This is extraordinarily high for domestic coal (nearly 60 percent higher on an energy content basis than the natural gas price appearing in the same table). The cost of coal production in Viet Nam is estimated to be $1.00 to $1.50/MMBtu (current prices to power generators are subsidized and about 35 percent lower). Applying the high end of the estimated Viet Nam coal production cost and the slight negative escalation rate estimated by the International Energy Agency (IEA 2010) yields $50/MWh (Case 3 of Table A4). Adding the potential value of carbon dioxide allowances yields a electricity cost of $90/MWh (Case 4 of Table A4). Cases 3 and 4 will be used in subsequent comparisons.

Table A4: Reference coal-fired supercritical steam-electric plant

Case	Total Plant Cost ($/kW)	Heat Rate (Btu/kWh)	Base Coal Price ($/MMBtu)	Annual Fuel Price Escalation	Capacity Factor	Levelized Energy Cost ($/MWh)
1. BDP2 HSR assumptions, normalized financing	2400[11]	8000	$5.51	Zero	80%	$80
2. Case 1 w/USDOE supercritical heat rate	2400	9000	$5.51	Zero	80%	$86
3. Case 2 w/current Viet Nam coal cost & IEA coal price escalation	2400	9000	$1.50	-0.1%	80%	$50
4. Case 3 w/CO_2 cost	2400	9000	$1.50	-0.1%	80%	$90

Diesel-fuelled, reciprocating engine generators. Diesel-fuelled, reciprocating engine generators are the conventional power supply for isolated loads and microgrids. Reciprocating engine-generators provide energy, firm capacity, and load-following capability for these small systems.

[11] MRC 2009 uses an EPC (engineering, procurement, and construction) cost of $2000/kW. Total plant cost also includes owner's costs, including infrastructure, project development, and administration. Typical owner's costs are about 20 percent of EPC costs, yielding total plant costs of $2400/kW. Total investment costs include financing fees, interest, and escalation incurred during construction and are typically 10–15 percent greater than total plant cost.

Though a mature technology, the thermal efficiency and air emissions of these units have improved in recent years. The cost of power from these units remains high, however, because of the cost of purchasing and transporting diesel fuel to the remote locations at which these units are typically located. Many alternative technologies available to isolated loads, such as solar photovoltaics and wind, cannot provide firm capacity. In microgrid applications, these energy displacement resources are valued on the basis of the variable cost of electricity from reciprocating engines. Other alternatives, such as small-scale biomass, geothermal hydropower, and hydrokinetic plants, may provide firm capacity and load following and are valued at the fully allocated cost of reciprocating units.

The levelized cost of electricity from a reference remote reciprocating engine is estimated to be about $290/MWh in the BDP2 Hydropower Sector Review (MRC 2009). The normalized financing assumptions of this study with an 8 percent discount rate yield $298/MWh for the same underlying assumptions (Case 1 of Table A5). The capital cost and heat rate of MRC (2009) appear reasonable. The high base year fuel cost is assumed to be attributable to the cost of transportation to remote locations. The capacity factor of 80 percent appearing in MRC 2009 is high for a unit supplying an isolated system; the more representative 70 percent value appearing in Table A5 is the reference value from MRC (2010b). Published fuel price information for remote Lower Mekong Basin locations is not consistent. The Hydropower Sector Review uses a base year distillate price of $27.58 and no real escalation, whereas BDP2 Technical Note 6 (MRC 2010b) uses a base year fuel price $16.63/MMBt and a 6 percent annual rate of escalation. March 9, 2011, diesel price at Singapore was $131.bbl, equivalent to $24.27/MMBtu, suggesting that the Hydropower Sector Review assumption is more realistic. However, the Hydropower Sector Review appears to assume no real escalation in diesel prices. Most analysts do expect continued real escalation of diesel prices and Case 2 of Table A5 incorporates the International Energy Agency estimate a long-term average annual escalation of crude of 0.5 percent (IEA 2010). This yields $315/MWh (Case 3 of Table A3). Finally, adding the potential value of carbon dioxide allowances raises levelized electricity cost to $349/MWh (Case 3 of Table A5).

As noted earlier, alternative electricity resources with firm capacity will compete against the full avoided cost of reciprocating engine-generators in an isolated grid application. Alternatives without firm capacity will compete on variable cost displacement. The fuel displacement values of the cases of Table A5 are shown in parentheses. Because of the high cost of fuel, variable costs are by far the largest component of the fully allocated cost.

Load-Side Options

Understanding of the potential for load-side services (energy efficiency improvements and peak demand shaving and shifting) is needed for fully informed decision-making regarding future electricity resource development. Assessment of load-side potential was not included within the scope of this work and is too complex for a quick assessment. Areas of potential may include transmission and distribution efficiency, motor efficiency, lighting, and reactive loads.

Table A5: Reference diesel-fired, reciprocating engine generator

Case	Total Plant Cost ($/kW)	Heat Rate (Btu/kWh)	Base Distillate Price ($/MMBtu)	Annual Fuel Price Escalation	Capacity Factor	Levelized Energy Cost [12]($/MWh)
1. BDP2 HSR assumptions, normalized financing	480[13]	10,000	$27.58	Zero	70%	$298
2. Case 1 w/ IEA crude price escalation	480	10,000	$27.58	0.5%	70%	$315 ($303)
3. Case 2 w/ CO_2 cost	480	10,000	$27.58	0.5%	70%	$349 ($337)

Comparisons of Resources

A summary comparison of electric power resource is provided in Table A6. Levelized energy cost comparisons of resources suitable for main grid service are provided in Figure A1. A similar comparison of resources suitable for microgrid and isolated load service is provided in Figure A2. These estimates were calculated using the levelized cost values using the energy production estimates and capital and O&M cost values developed as described in the text for the various electricity generation alternatives. MicroFin, an Excel workbook for calculating year-by-year and levelized lifecycle revenue requirements, was used for calculating these costs. MicroFin was developed and maintained at the Bonneville Power Administration and the Northwest Power and Conservation Council, and is publicly available on request from the Northwest Power and Conservation Council.

Figure A1 depicts the direct project costs of resources suitable for main grid service. On a normalized plant cost basis, the reference gas combined-cycle plant is 12 percent less expensive than the reference supercritical coal unit. Because of gas price uncertainty and uncertain long-term Vietnamese coal costs, this difference may not be significant. With consideration of CO_2 production, the comparative cost of the two thermal options tilts strongly in favor of the gas unit because of the much greater carbon content of coal and lower thermal efficiency of the steam unit. Considering the possible future cost of carbon dioxide production (or, alternatively, the value of the lower CO_2 production of the natural gas unit), the project cost of the combined-cycle plant is less than 70 percent of the cost of the reference coal unit.

On a normalized project cost basis, excluding possible CO_2 cost penalties, only four of the proposed hydroelectric projects (Thakho, Don Sahong, Xayaburi and Sanakham) have a lower

[12] 80 percent capacity factor.

[13] MRC (2009) uses an EPC (engineering, procurement, and construction) cost of $2,000/kW. Total plant cost also includes owner's costs, including infrastructure, project development, and administration. Typical owner's costs are about 20 percent of EPC costs, yielding total plant costs of $2,400/kW. Total investment costs include financing fees and interest and escalation incurred during construction and are typically 10–15 percent greater than total plant cost.

expected project cost than a natural gas fired combined-cycle plant. Considering the possible future cost of CO_2 production, all but one of the hydro projects (Stung Treng) have lower project costs than the reference combined-cycle plant. The normalized cost of Stung Treng is significantly higher than the cost of the gas combined-cycle unit or the other mainstream hydro projects.

Near-term (commercial) alternatives to fossil thermal units or mainstream hydropower with large-scale (tens of thousands of GWh) energy production potential include utility-scale wind power, utility-scale solar photovoltaics, parabolic trough solar thermal, and possibly an aggregation of diversion hydropower projects. Of these, only diversion hydropower has the potential to be cost-competitive with conventional sources in the near-term, though wind costs may decline to the cost-competitive levels seen in the first decade of the century as turbine production catches demand and lower-cost wind turbines are increasingly available from China and India. Parabolic trough, solar-thermal plants are an emerging commercial technology, but require the strong, direct, normal, solar radiation characteristic of arid and high elevation sites for most efficient operation. Smaller-scale, potentially competitive contributors in the near-to midterm include conventional steam and biogas plants fueled by bioresidues and hydropower retrofits to nonpower, water control projects.

Reciprocating engines operating on biodiesel from jatropha or other sources may become commercially available for main grid service over the longer term. The engine-generator technology is commercially available, however many years may be required to develop a viable biodiesel industry. Moreover, transportation demand may result in biofuel prices that cannot be sustained by the electric sector. Finally, marine type hydrokinetic turbines may mature to a fully commercial technology within a decade, opening the potential for development of moderate amounts of generation in the Mekong Delta and along the southern Viet Nam and Cambodian coast. Capital costs must drop by a factor of five for the resource to become competitive. Not shown in Figure A1 is geothermal. While the technology is mature, the resource potential of the LMB appears to be very limited. Finally, demand growth might be tempered by aggressive energy efficiency measures. In many areas, energy efficiency measures are much more cost-effective than conventional fossil thermal technology and far more competitive than most resources considered here.

Resources available for isolated load service in the near- to midterm (2015–2020). Figure A2 depicts the direct project costs of resources suitable for service of isolated loads and microgrids. The contrast with Figure A1 is striking in that every alternative is more potentially cost-effective than the reciprocating engines currently used to service these loads. However, of the alternatives, only solar photovoltaics use a universally available resource; all others use energy resources that may or may not be available at a given location. Moreover, electricity from solar photovoltaics is nearly as expensive as electricity from diesel-fuelled reciprocating engine and photovoltaics provides no firm capacity. A companion firm supply, such as an engine generator or battery storage, is needed for firm service. All other alternatives shown (and community-scale wind, not shown) are commercially available and potentially economically attractive where available. Moreover all (except for wind) have the potential of providing firm capacity. All technologies shown in Figure A2 are commercially mature except for biodiesel and river current hydrokinetics. A decade may be required to commercialize the latter resources.

3. Observations Regarding Electricity Resource Planning and Recommendations for Further Research and Development on Promising Alternative Resources in the LMB

This section provides recommendations for consideration in future studies on alternative resources for power generation in the Mekong. As mentioned above, the BDP2 only evaluated impacts of the proposed countries' water resources development plans, which include hydropower projects on the mainstream and tributaries; it did not seek to assess the power generation plans or examine alternatives to hydropower dams. However, the necessity to further investigate power generation options has been acknowledged by the MRC in its adopted IWRM-based Strategy. Initial recommendations are presented here which may be useful in MRC's considerations to further research promising alternative power resources in the LMB.

Incorporate explicit consideration of risk and uncertainty into electric power planning. Scenario and sensitivity analysis are used for consideration of risk and uncertainty (MRC 2010a, Annex 4 Para 3.1.4). In view of the potential significance and uncertain nature of the environmental and socioeconomic consequences of mainstream hydropower development, consideration should be given to use of planning methodologies that explicitly incorporate uncertainty and risk. These include methods such a portfolio risk analysis, derived from the financial industry. These enable explicit consideration of uncertainties and portrayal of expected and severe outcomes.

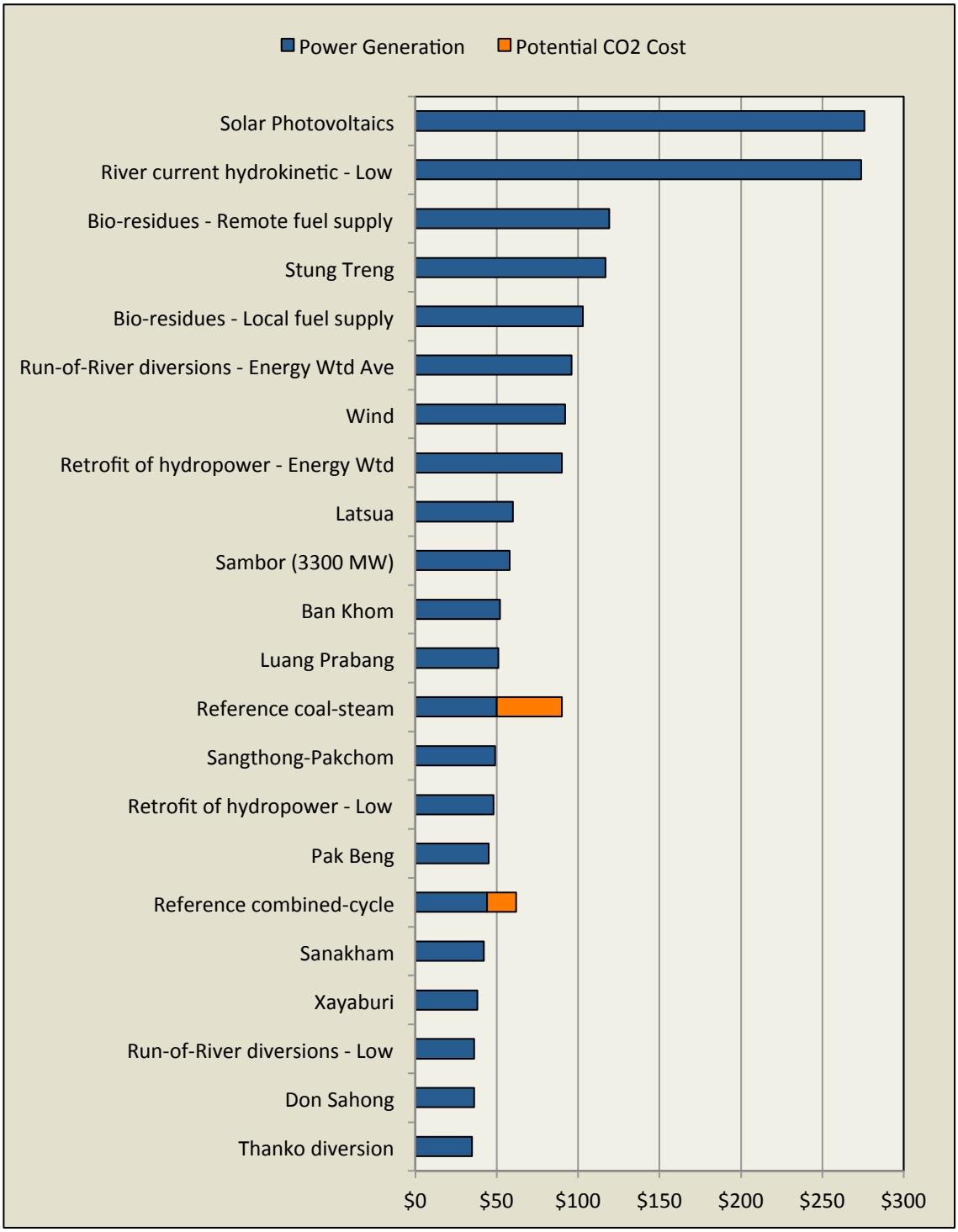
Further assess the potential for low-cost diversion hydropower projects. Though the cost of individual projects will vary widely, diversion hydroelectric projects appear to have the potential of providing capacity and energy services at costs comparable to proposed mainstream impoundment projects. Moreover, the environmental and social impacts of diversion projects are likely to be less profound and better understood than those of major impoundments. Although the resource potential of diversions is likely to be much less than the potential from mainstream impoundments, diversion projects could serve local load growth until the environmental consequences of mainstream impoundments are better understood and the effectiveness of mitigating measures is improved.

Evaluation of replacement power cost. The estimated cost of energy from the proposed Mekong mainstream hydropower projects is about 20 percent less than the cost of power from alternative thermal generation options in Viet Nam and Thailand (MRC 2009). Given that the greatest portion of the value of these projects rests on power value, moderate changes in assumptions regarding the cost of alternative resources could significantly affect the net value of these projects. A review of the assumptions used to calculate the replacement cost of power (MRC 2009, Annex B; MRC 2010b) suggests several questionable assumptions, some of which might result in increased cost of replacement power and some that might result in decreased cost of replacement power.

Table A6: Summary comparison of power generation resources available within the Lower Mekong Basin countries

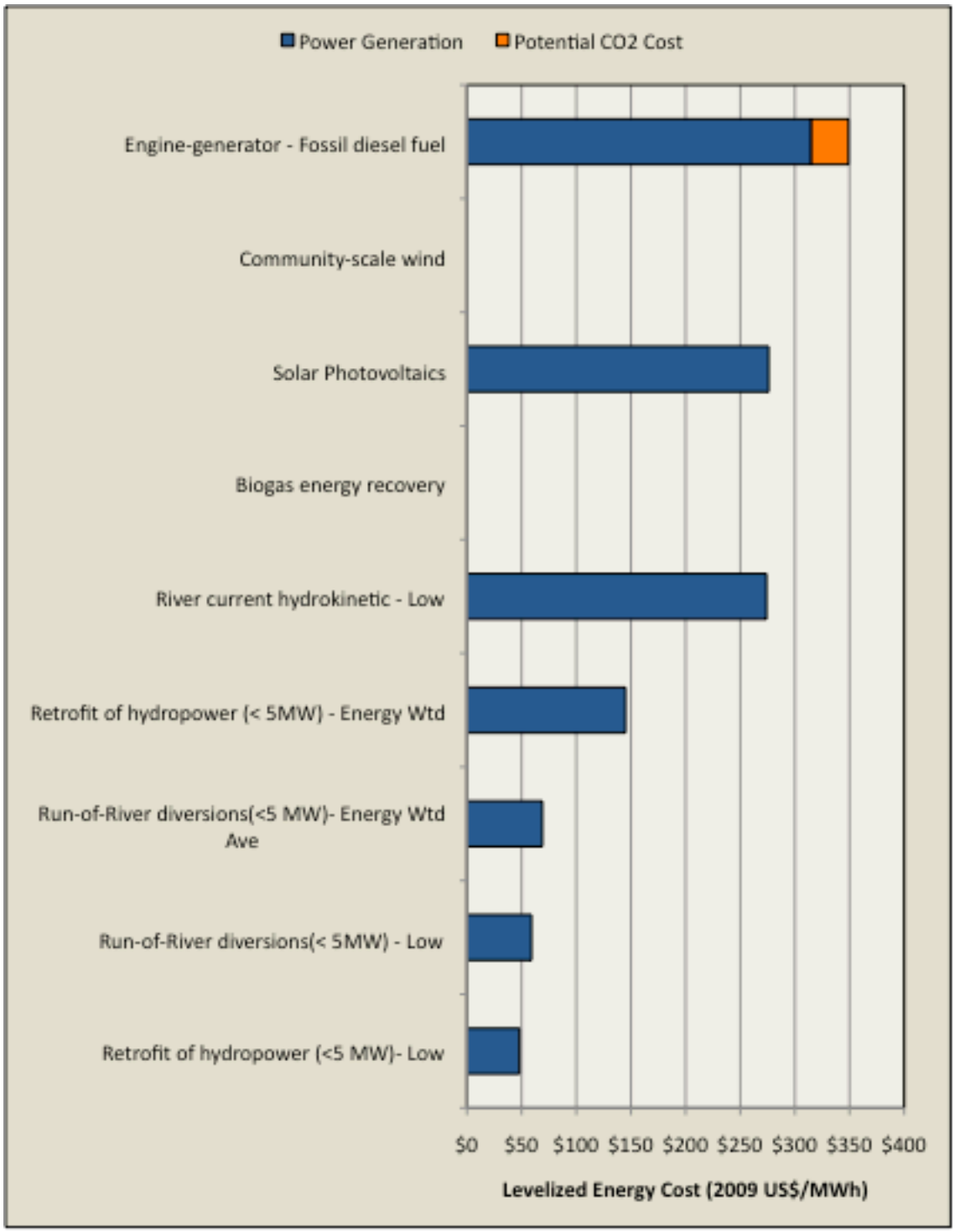
Resource	Application	Electrical Products	Commercial Status	Earliest Operation (New project)	Typical Project Size (MW)	Resource Potential	Key Issues
Natural gas combined-cycle	Main grid bulk power supply	Energy, firm capacity, load-following	Mature	2015	Hundreds of MW	Extensive S. China Sea resources	Natural gas price uncertainty
Supercritical steam coal	Main grid bulk power supply	Bulk energy, firm capacity	Mature	2018	Hundreds of MW	Extensive Viet Nam reserves	Greenhouse gas control
Impoundment hydropower	Main grid bulk power supply	Energy, firm capacity, load-following	Mature	2018	Tens to thousands of MW		Stream blockage, reduction in flow velocity, flooding
Reciprocating engine-generators	Isolated grid or main grid load following	Energy, firm capacity, load-following	Mature	2013	Hundreds of kW to several MW	Not energy limited	Fuel cost
Diversion hydropower (run-of-river)	Bulk power supply or isolated grid	Energy, firm capacity, load following	Mature	2015	Tens of kW to hundreds of MW	Unknown potential	Maintenance of minimum in-stream flow
Retrofit hydropower (run-of-release)	Bulk power supply or isolated grid	Energy, firm capacity	Mature	2015	Tens of kW to tens of MW	Unknown potential	Limited site availability
River current hydrokinetic generation	Isolated grid	Energy, firm capacity	Early demonstration	2020	Tens of kW to several MW	Unknown potential	Technology commercialization
Ocean wave	Bulk power supply or isolated grid	Energy	Early demonstration	2020	Tens of kW to tens of MW	Inadequate energy density	Technology commercialization, competing sea space
Ocean and tidal current	Bulk power supply or isolated grid	Energy	Commercial pilot	2020	Hundreds of kW to tens of MW	Near shore and Mekong Delta potential	Technology commercialization
Salinity gradient			Conceptual				Technical immaturity, salinity intrusion
Bio-residues	Bulk power supply or isolated grid	Energy, firm capacity	Mature		Hundreds of kW to tens of MW	Cassava, palm oil, rice, sugarcane and timber residues	
Energy crops	Bulk power supply or isolated grid	Energy, firm capacity, load-following	Demonstration		Hundreds of kW to tens of MW	Jatropha cropping potential	Cost and sustainability of jatropha cropping
Geothermal	Bulk power supply or isolated grid	Energy, firm capacity	Mature		Tens of kW to tens of MW	Limited potential N. Thailand	
Ocean Thermal Energy Conversion	Bulk power supply or isolated grid	Energy, firm capacity	Early demonstration		Tens of MW	No nearshore potential	Technical immaturity, lack of near-shore resource
Solar photovoltaics	Bulk power supply or isolated grid	Energy	Mature	2012		Good-quality global resource	
Solar thermal	Bulk power supply or isolated grid	Energy,	Early commercial			Fair quality direct normal resource	
Windpower	Bulk power supply or isolated grid	Energy	Mature		Tens of kW to hundreds of MW	Good to excellent resource	Conflict w/forest management

Figure A1: Energy cost of resources for main grid service (2009 US$/MWh)



Source: Author's estimates.

Figure A2: Energy cost of resources for microgrid and isolated load service (2009 US$/MWh)



Source: Author's estimates

Alternative resource development for isolated loads and microgrids. To the extent that development opportunities are available, run-of-river diversion projects and addition of power generation to nonpower water control structures appear to offer the most economic alternatives for

supplementing or replacing diesel generation for microgrid and isolated load service. If not yet accomplished, a detailed survey of development opportunities should be undertaken. Solar photovoltaics, biodiesel, and river current hydrokinetic technologies, though considerably more expensive than hydropower options, also appear to be competitive with fossil diesel. These should be considered where hydropower development opportunities are unavailable. Solar photovoltaic technology is well established and requires little research or development beyond efforts to develop standard packages suitable for typical applications. Jatropha may be promising source of biodiesel fuel for existing and new reciprocating engine generators and the feasibility of establishing sustainable cultivation and processing should be investigated. River current hydrokinetic technology is at an early stage of development and the objective should be to develop robust standardized modular designs suitable for domestic fabrication and deployment. A suggested approach is as follows:

- Commence a hydrokinetic site assessment with the initial objective of identifying a set of representative sites at which demonstration projects can be undertaken.
- Fully characterize demonstration sites.
- Design, construct, and install units at these sites. Use a variety of machines incorporating design variations where the value and cost of these is not well understood.
- Operate and monitor demonstration units with the objective of developing a set of commercial production designs optimized for representative LMB sites.
- If results are favorable, expand site inventory characterization basin-wide.
- Commence general deployment of production designs at favorable sites.
- Maintain follow-up monitoring to ensure machines remain in-service and are properly maintained. Use operating experience to refine operating and maintenance protocols, equipment and plant design.

4. Other Renewable Generating Options

Agricultural and Other Bio-Residues

Conventional, steam-electric plants with or without CHP will be the chief technology for electricity generation using solid bio-residues in the near term. These units typically range from five to 50 megawatts in capacity; capacity frequently being determined by available fuel supply within economic transport distance. Modular, bio-gasification plants are under development and may be introduced within the next several years. Modular units would open the possibility of bringing the plant to the fuel, thereby expanding the potential fuel supply, reducing fuel transportation costs, and improving the economics of plant operation. Available fuels include residues from the harvesting and processing of cassava, palm oil, rice, sugarcane, and timber.

Dedicated Energy Crops

Dedicated energy crops are not usually considered economically feasible as a fuel for electricity production because the value of the energy product (usually ethanol or biodiesel) for transportation is greater than its value for electricity generation. Production of biodiesel in

areas of the Lower Mekong Basin suitable for growing jatropha may be an exception to this rule. Biodiesel obtained from jatropha seed can fuel the reciprocating engine generators that provide local electricity supply in many areas. Moreover, the husks and press cake residues of jatropha seed processing can be processed in anaerobic digesters to yield a biogas fuel suitable for gas-fired, reciprocating engine generators.

Jatropha (*Jatropha curcas*) is a drought-tolerant perennial shrub native to Central and South America. Though the plant is said to thrive on marginal soils, recent evidence suggests that economic oil yield requires abundant water and nitrogen and phosphorous fertilization (Achten et al. 2008). Jatropha produces inedible seed with high oil content. The oil can be used directly as a biodiesel blend or refined for use as neat biodiesel. Widely planted in tropical and subtropical countries as hedgerow, plantation cultivation of jatropha for oil and glycerin (a byproduct of refining) is increasing, especially in Brazil, the Philippines, India, and China.

The seed is obtained by manually collecting then hulling the mature fruit pods. The seed is sun or oven dried, then pressed to extract the oil. Solvent extraction methods are also available. Following removal of particulates by filtering or centrifugation, the oil can be used directly or blended with fossil diesel in older or low-speed engines. Further refining (transesterification) produces a biodiesel compliant with European and North American standards, plus glycerol, a marketable byproduct. The biodiesel can be used neat or blended with fossil diesel or methanol. The press cake can be used fertilizer or as feedstock for anaerobic digesters to produce additional fuel in the form of biogas.

Biodiesel can substitute for imported diesel fuel in the reciprocating engine generator sets used for community-scale or isolated grids as well as tractor, irrigation pump, and road vehicle engines. Crude jatropha oil is suitable for older vehicles and stationary engines, but newer diesels, including the high-efficiency generating units now available require jatropha biodiesel. Reciprocating engines are expected to remain an important component of community and isolated grid power systems, even as the penetration of renewable sources increases, to provide firm capacity, load-following capability, and dry season energy.

Limited and poorly documented information is available for jatropha biodiesel production costs. Jatropha oil was reported to cost approximately US$43/bbl at the time of the 2008 Air New Zealand flight test using refined jatropha oil as jet fuel. The Indian Planning Commission reports production costs of 26 rupees (approximately US$41/bbl at current exchange rates) per liter. At an estimated calorific value of about 5,500 MJ/bbl, this equates to US$7.90 to $8.20/MMbtu. In comparison, the cost of diesel fuel for replacement cost of power using diesel generators used by the MRC for the Basin Development Plan Power Benefits assessment (MRC 2010b) is US$16.63/MMBtu, forecast to escalate 6 percent annually. The comfortable spread between jatropha biodiesel prices and forecast diesel prices suggests that jatropha biodiesel has the potential of being a competitive domestic source of fuel for the reciprocating engines serving isolated electrical grids.

In addition to providing a competitive supply of renewable energy, jatropha biodiesel production could provide rural economic development and employment benefits, help restore degraded land, and enhance national energy security.

Jatropha has been heavily promoted in recent years and aggressive programs are underway in many countries, including Cambodia and Laos, to establish jatropha plantations for biodiesel production for export and domestic use. Some of these efforts have fallen short of official goals and important issues remain to be resolved. Domestic cultivars having reliable yield need to be developed. Systematic study of Jatropha agronomy is needed including optimal cropping schedules, spacing, irrigation, propagation, and fertilization. Finally, the naturally present toxins in jatropha fruit, the chemicals used in processing, and the air quality effects of jatropha biodiesel combustion warrant study.

Though small-scale pressing and refining equipment suitable for decentralized production is available, plantation agriculture tends to be more efficient than small-scale operations. Large-scale growing and processing operations, however, can present negative consequences including deforestation and accompanying ecological, hydrological, and erosion concerns; competition for land for food supply; and increased demand for irrigation and pesticides. Equity issues arise. Large-scale operations are often controlled by private concessions and national and local economic benefits are foregone. Plantation growers will seek out prime land to maximize production, pressuring small-scale farming and possibly raising food prices.

Other issues concern energy balance and global warming potential. Available studies suggest that the life-cycle energy balance of jatropha biodiesel is generally positive, providing that the byproducts (husks, seed cake, glycerol) are efficiently used. The global warming impact of jatropha biodiesel appears to be significantly less than fossil diesel, though it would include any forest clearing undertaken to establish jatropha cultivation.

Geothermal

The crustal heat of the earth can be used to produce electricity and useful thermal energy. Conventional geothermal development use requires the presence of fluids at sufficient temperature within a feasible drilling depth. Flashed steam technology can be used for intermediate to high temperature resources; binary fluid technology is used for low to intermediate temperature resources. Conventional geothermal technology is commercially mature, but suitable sites are limited. Engineered (or "enhanced") geothermal technology requires only sufficient temperature and fracturable rock at feasible drilling depth. The fluid is supplied by injecting water from the surface following the creation of heat transfer surfaces by fracturing. Enhanced geothermal technology is in the early demonstration stage and, if successfully commercialized, is expected to greatly expand areas suitable for geothermal resource development.

Geothermal plants provide firm capacity and energy, but limited load-following capability. Binary technology with geothermal fluid reinjection (the typical configuration) has few environmental impacts. The principal risk is associated with the substantial capital investment needed to prove up a resource prior to financing plant construction.

One small (0.3 MW) geothermal unit is operating near the community of Fang in northern Thailand. Modest opportunities for additional geothermal development using binary-cycle geothermal technology appear to be available in this area. The Himalayan Geothermal Belt, lying

slightly north of the intersection of the Indian and Asiatic tectonic plates extends from Kashmir through Tibet, to Yunnan province of China, and possibly down into northern Myanmar and Thailand (Figure 1 of Eckstein et al. 2010). Seven intermediate temperature (150–200°C) geothermal systems have been identified within this area of northern Thailand. One near Fang is the location of the only reported operating geothermal power plant within the four LMB countries. This 0.3 MW binary unit with waste heat recovery has successfully operated on 117°C water since 1989. Though the presence of additional geothermal resource areas in Thailand is reported no further information was located regarding other geothermal resources in Thailand or other LMB countries. Binary geothermal technology has progressed rapidly in recent years and modular binary geothermal units ranging from 250 kW to about 15 MW in capacity are commercially available. The cost of recently developed, small (15 MW) binary plants in western North America is approximately $85/MWh (2009 US$, busbar, independent developer financing, no incentives).

Solar

Electric power can be produced from solar radiation using solar photovoltaic or solar thermal technologies. Photovoltaic plants convert sunlight to electricity using solid-state devices. Because no combustion or other chemical reactions are involved, power production is emission-free. No water is consumed other than for periodic cleaning. Power output is variable and battery storage or a backup power source is required for isolated loads demanding a constant supply. Grid-connected installations require firm capacity and balancing reserves. However, balancing reserve requirements may be reduced by distributing many small plants over a wide geographic area, dampening cloud-driven ramp rates. Most commercial photovoltaic devices are nonconcentrating, in that the sunlight is not concentrated using mirrors or lenses.

Solar thermal power generation (also referred to as concentrating solar power (CSP) uses lenses or mirrors to concentrate solar radiation on a heat exchanger to heat a working fluid. The working fluid is used directly or through a secondary working fluid to power a turbine generator. CSP technologies are categorized by the design of the concentrator and the type of thermal engine. The three basic types are parabolic trough, central receiver, and Sterling dish. Nonconcentrating devices utilize global radiation, i.e., direct solar radiation plus the diffuse sky and cloud radiation. Concentrating devices are limited to direct solar radiation and are more suitable for cloud-free locations.

Good-quality solar resources ranging from 5.5 to 6.0 kWh/m^2/day annual average are found in southern Laos, northern Cambodia, and northern and central Thailand. Fair-quality resources (5.0–5.5 kWh/m^2/day annual average) are found throughout the rest of the LMB. Direct normal resources in the region are fair, the best being 4.5 to 5.0 kWh/m^2/day annual average in southern Laos, northern Cambodia, and east-central Thailand. Despite the quality of resource and coincidence with air conditioning loads, relatively little development of solar generation is reported. Figures are available only for Thailand, which reports 34 megawatts of distributed photovoltaic capacity. Substantial potential using nonconcentrating photovoltaic devices is available. This resource can be used in off-grid, community-scale grid, and utility-scale grid

applications. Grid applications normally require use of inverters and safety disconnect equipment, adding to the cost and reducing the output of these systems.

Wind

The most recent comprehensive assessment of the wind resources of the Lower Mekong Basin is the 2001 Wind Energy Resource Atlas of Southeast Asia prepared by TrueWind Solutions for the World Bank (TrueWind 2001). This assessment estimated wind resource potential for both large and small turbines (65 meter and 30 meter hub height). The assessment indicates that good to excellent potential (average annual wind speeds of 7.0 m/s or greater) for large-scale wind development is present in the mountains of central and southern Viet Nam, central Laos, and in the coastal area of southern and south-central Viet Nam. Scattered areas of good potential are also present in central and western Thailand. The extensive shallow seafloor off the southern coast of Viet Nam suggests the potential for offshore wind development using monopole turbine foundations as used in the North Sea. LMB winds are at their strongest in the December through February and June through August periods.

Areas in or near the LMB classed as good or better (average annual wind speeds of 5.0 m/s, or greater) for small turbines include the aforementioned areas plus east-central Thailand, scattered areas of Cambodia, south-central Laos, and central and southern Viet Nam.

Ocean Thermal Energy Conversion

Solar radiation incident on tropical oceans can create a surface-to-depth temperature differential of 20°C, or more. This is sufficient for generation of electricity from the potential energy of the temperature differential using Rankine cycle heat engines.

The leading ocean thermal energy conversion (OTEC) concept would use binary-cycle technology. Binary technology would use seawater from the heated surface layer to evaporate a low-boiling point working fluid such as ammonia. The vaporized working fluid would drive a turbine generator, then be condensed in a heat exchanger cooled by cold seawater pumped from depth. The condensate would then be repressurized with pumps for return to the evaporator. The pumps, heat exchangers, and turbine generators would be located on a floating or semisubmerged platform, or shore side in favorable locations. The low temperature differential limits recovery efficiency to less than 10 percent, necessitating the pumping of extremely large volumes of seawater. A 100 MW plant, for example, would require a 10-meter diameter, cold-water intake at least 1,000 m in length. Though the energy supply is "free," the scale of the cold-water intake, seawater pumps, and heat exchangers will result in very high unit capital cost. Preliminary cost estimates of commercially mature facilities range from $7,000–17,000/kW, yielding electricity at $120–330 per MWh.

OTEC could provide significant amounts of renewable, baseload electricity with little environmental impact. Byproducts of plant operation could include desalinated water, chilled water for air conditioning, nutrient and cold water supply for aquaculture, and feedstock for extraction of dissolved minerals.

OTEC concepts were first proposed in the nineteenth century and significant research commenced in the late 1970s. Technical difficulties and persistently low fossil energy costs resulted in termination of most of this work during the 1980s. Rising oil prices, the resurgence of interest in low-carbon forms of energy, and efforts to achieve national energy security have revived interest in OTEC technology. At least two serious efforts are underway to develop the technology, including a 10-megawatt pilot plant for Tahiti and a five- to 10-megawatt pilot plant in Hawaii. Ten years or more are expected before operation of the first commercial plant. It is likely that the earliest commercial development of OTEC technology will be at tropical islands currently relying on imported oil for electricity and at arid sites benefitting from desalinated water byproduct.

Surface temperatures of the South China Sea are reported to average 29°C and temperatures of 3°C have been measured at 2,900 meters in the Sabah trough. However, the Gulf of Thailand and the westerly portion of the South China Sea lie over a continental shelf of less than 200 meters depth, whereas the cold water layer lies at 1,000 meters, or deeper. Of the LMB countries, only the central coast of Viet Nam approaches within 100 km of depths of 1,000 meters. This distance is likely to render OTEC an infeasible option for energy supply to the LMB countries for the foreseeable future.

Appendix B:
Social Impacts and Recommendations for Future Assessments

1. Insights from Additional Resources

Social impact assessment in basin-scale planning purposes (as opposed to assessment of individual projects) is a complex issue, which is constrained by limited knowledge of impact processes and data availability. The challenge of social impact assessment is particularly relevant for the planning processes in the LMB. Despite MRC's efforts to provide analytical inputs on the subject under the BDP and the SEA, key knowledge gaps remain with regards to the distribution of impacts from the key water resource developments, as currently planned by LMB governments, on different groups of Mekong stakeholders. In addition, the likely effectiveness of proposed mitigation and compensatory measures also presents a major source of risk and uncertainty in assessing the cumulative costs and benefits of the proposed projects. Within the time-scales of the planning periods under consideration, the social and socioeconomic landscapes can also be expected to change through exogenous factors (e.g., urbanization, education, health, poverty alleviation programs, etc.), such that the livelihoods situation in the LMB today within the potentially affected population will not be the same in 10 or 20 years time. Such a dynamic situation increases the analytical complexity in establishing a baseline situation against which social impacts of developments could be assessed.

Building on the social impact assessment aspects of the BDP and SEA, this appendix reviews some additional materials which further elucidate the current socioeconomic situation in the Mekong Basin and the social impacts of previous, large, infrastructure developments in the region. Given the wealth of literature that exists on the subject, this appendix chooses to focus on key insights from selected case studies which are especially useful in improving the LMB water resources planning processes, including those related to mainstream and tributary hydropower projects.

Insights from additional resources on current socioeconomic and livelihood conditions of the population in the LMB, and potential social and environmental impacts from new projects, are highlighted below:

a) Environmental Impact Assessment (EIA) studies (Sangha and Bunnarith 2006) have been inadequate, especially regarding the identification of and proposed mitigation for transboundary impacts.

b) While hydropower dams are expected to generate high revenues for the host country, livelihoods of affected people within the country may not be improved as much as expected from the development, as demonstrated by the past experience from several hydropower projects including the Pak Mun dam (PAP 2011), hydropower developments in the Sesan, Sekong, Srepok (3S) transboundary basin, and the Theun-Hinboun hydropower project (Norplan 2008).

c) Even when mitigation and compensation measures are in place, they may not be effective for the affected populations. Previous experience from the Pak Mun dam in Thailand and the Theun-Hinboun dam in Lao PDR illustrates the inadequacy of these measures. However, recent experience from the Nam Theun 2 project in Lao PDR suggests that putting in place a comprehensive and effective compensation and mitigation scheme is also possible when the government carefully negotiates a concession agreement with the developer.

i. Pak Mun Case Study, Thailand

A review of the Pak Mun dam experience revealed that the affected communities did not participate in the planning process for the project. As a result, environmental and social costs, which had to be borne by the communities, were not adequately taken into consideration. In addition, the displaced community members argued that both environmental and social costs—especially the intangible cost of loss of cultural heritage, traditional livelihood, and social breakdown—cannot be fully compensated and mitigated.

Table A2.1: Summary of Pak Mun Consultation Results

Issues	Before dam construction	After dam construction
Food security	Easy to find food	More difficult because nearby ecosystem has been degraded
Debt	Little	More debt since communities are no longer self-reliant
Community integrity	High	Community breakdown
Culture and norms	United	Collapsed
Revenue from tourism	Higher	Lower

Source: Sub-committee for consultation with the people affected by the Pak Mun dam, 2010

ii. Theun Hinboun Case Study, Lao PDR

Darasouk (2009) researched the implementation of the Theun Hinboun Power Company (THPC) mitigation and compensation plan in Lao PDR. The company adopted a comprehensive 10-year mitigation and compensation plan following the construction of the Theun Hinboun hydropower dam, which inadvertently damaged the livelihood of local populations in the project area. Her research found that the plan "was significantly delayed by documentation requirements and late availability of fund." As an example of a mitigation measured proposed for riparian communities affected by the project, "the dry season paddy land with irrigation system and other agriculture lands planned for are still pending (yet to be implemented). Therefore it can be concluded that these proposed packages are inadequate to restore livelihood and food security for recipient river communities in the first two years after relocation."

In addition, Darasouk noted that "The four impacted communities studied still have no access to electricity and remain with poor access roads… The THPC compensation and mitigation program to deal with these impacts was totally inadequate. As examples, the drinking water supply in Khen village failed and cannot be used, three years of dry season rice practice for both Khen village and Kengkhot village were unsuccessful, and many households remain in debt to the savings and credit fund established by the project… The mitigation and compensation program initiated by THPC in 2001 to address the project's social and environmental impacts has not lived up to expectations and is failing to restore people's livelihoods" (Darasouk 2009).

Based on the above observations, Darasouk (2009) concluded that the THPC experience represents a clear case of failure of existing institutions to fulfill their promises and meet villagers' needs. Darasouk analyzed key factors that contributed to the failure of these mitigation and compensation programs and summarized that:

- Project-affected people (PAP) were not properly identified, and upstream and downstream communities were excluded.
- Important environmental impacts emerged that had not been anticipated in the planning documents. For example, dynamic floods and erratic water flow changed after the project.
- Mitigation and compensation packages for the PAP were far from adequate, with no direct compensation or cash compensation available for physical and livelihood losses.
- New lands allocated to the displaced communities are very poor in terms of their agricultural potential.
- Substitute livelihood options for the communities failed or were unsustainable.
- Deforestation of previously unused mountainous and watershed areas for upland agriculture turned out to be severe, with the backfiring effect of reducing hydropower productivity.

iii. Nam Theun 2 Case Study, Lao PDR

The Nam Theun 2 hydropower project in Lao PDR is a recent project, which is recognized as having achieved a better outcome in compensation and mitigation for the PAP. Despite some unsuccessful mitigation programs to offset the social impact and loss of ecosystem services (such as the setting up of a Village Forest Association (VFA) at the Nakai Plateau), and some negative unforeseen impact on biomass decay releasing methane and CO_2, the Nam Theun 2 project has put in place several key mitigation and compensation measures with clear evidence of success. While some criticized that these programs and measures started much later after the dam operation when vast natural capital had already been depleted, key elements of these programs are effective and could provide a relevant example for future projects.

Specifically, the Nam Theun 2 Power Company (NTPC) under the concession agreement with Lao PDR Government has instituted an environmental management and monitoring system to carry out these programs:

1. *Artificial habitats* were created to replace habitat lost, such as eight "salt lick" locations for ungulates and 30 artificial wetlands.
2. A *monitoring program* was established in cooperation with the Watershed Management and Protection Authority (WMPA) with funding set aside by NTPC for long term monitoring for conservation purposes.
3. Under the *Wildlife Management and Monitoring Program*, some new animals were discovered, such as Muntjak and Chinese Swamp Cypress in the National Protected Area (NPA) and corridor zones. Fish inventory of both upstream and downstream river species is also included in this program.
4. Under the *Biodiversity Conservation Program*, a turtle conservation program was put in place where animals were collected and rehabilitated in their natural habitat.
5. An *Invasive Species Program* was put in place whereby some species were required to be removed or destroyed for health and safety reasons.
6. A *Study Program for the Threatened Species* was established. This program can be a valuable lesson for future development projects that could cause disturbance or interruption of ecosystem health and habitat, potentially resulting in a permanent or irreversible damage on unknown or undiscovered plant or animal species with unknown function in the food cycle.
7. The *Environmental Education Program (EEP)* was implemented on the Nakai Plateau to instill awareness and reduce exploitative danger to wildlife.

d) Environmental pollution can result from aquaculture development (Loc et al. 2009).

e) Seawater intrusion and sediment loss are likely to affect agricultural production in the Mekong (Nguyen Xuan Hien 2009).

The BDP notes that the Mekong Delta's population of more than 17 million is directly impacted by changes in upstream flow and water quality conditions. These riverine populations are also the segment of basin population most vulnerable to the impacts of climate change, particularly potential sea level rise. Potential changes that will affect livelihoods of these populations, especially those in the delta, are not yet analyzed in detail as part of the BDP. The BDP does however provide a preliminary estimate of the number of vulnerable resource users in this category. In future water resource planning discussions in the Mekong, detailed assessments should be conducted on the impacts of these key changes on flow and sediment conditions which will affect the delta, especially with regards to agricultural lands and productivity, fisheries productivity, and lost fisheries-related activities and occupations.

f) Wealth distribution problems (disparity between rich and poor) may arise from mainstream development projects (Pongpaichit 2009).

g) Aquaculture may not replace lost captured fisheries in terms of affordability for local populations and nutrition (Hall and Manorom undated).

While the scenario analyses in the BDP2 report pointed to positive impacts for some key socioeconomic sectors, such as employment and agriculture, significant social impacts,

especially negative ones from lost capture fisheries, are anticipated at the local level. Lost capture fisheries is a key issue of concern for future social impact assessments in the Mekong due to its critical linkage to food security of local people along stretches of the river. For example, total fish consumption in Lao PDR is currently estimated to be 204,800 tons. Based on a population of five million people, the average annual per capita fish consumption would be 42.2 kg. Capture fisheries contribute the largest proportion of total fish consumption (85 percent or182,700 tons), with the remainder coming from reservoir fish catch (16,700 tons) and aquaculture production (5,400 tons) (Hall and Manorom undated). It would take a vast expansion of reservoir fishing success to make up the difference if the country loses a minimum of 25 percent of its 182,700 tons of annual river fish consumption. In addition, increased aquaculture production in the delta may be geared more to export markets than to domestic supplies and there is no guarantee that fish sourced from remote aquaculture areas will be affordable to people who normally catch their own supply.

h) The importance of sediment deposition to agricultural productivity and riverbank gardens should be further analysed (Gajaseni 1995, 2005, 2006).

Based on field studies along the Mekong from Northern Lao (Bokaeo) down to Southern Lao (Champasak), and discussions by the Mae Fah Luang University (MFU) study team members with various groups and individuals at the Procedure for Notification, Prior Consultation, and Agreement (PNPCA)-related public consultation meetings in Thailand in 2011, essentially *every* rural family living along the Mekong practices riverbank gardening in the dry season (from January to May). Each riparian family in Thailand, for example, earns 50,000–70,000 baht from its annual riverbank agriculture. These riverbank gardens are only possible due to the nutrients provided by the Mekong's natural river flows. Should these flows diminish markedly due to construction of mainstream or tributary dams or other diversion activities, these important food and income sources could disappear. For comparison, in Thailand's Chao Phraya River nutrients from natural services of the river are equivalent to adding 62 kg per hectare of nitrogen and phosphorus fertilizers per year (Gajaseni 1995).

i) Stakeholders' access to required project documents was limited during the PNPCA consultation process for Xayaburi, reflecting the need for project proponents to improve the quality of future public consultation processes.

From the discussion that took place during the public consultation organized as part of the PNPCA for Xayaburi by the Thai National Mekong Committee at Chiang Kong on January 22, 2011, the people along the Mekong River indicated that major project documents were not available for their review for an adequate period of time prior to the consultation. During the event, the people also perceived that there would be substantial social impacts, especially for food security and loss of traditional knowledge and local identity, if these ecosystem services provided by the river were altered by major development projects. The importance of adequate and informed consultation on these subjects was highlighted during the discussion.

j) Cultural service losses are irreplaceable and permanent. Indigenous knowledge learned over generations, even centuries, may evaporate if planning assessments do not properly factor in the value of this important ecosystem service of the Mekong.

People of the Mekong Basin recognize highly diverse ecosystem components of their region, often features that are unknown or unrecognized by academic ecologists. For example, local people can identify 11 systems that influence fish diversity in their fishing areas, each with a different structure, function, and dynamics. The Mekong fishermen use 71 different types of fishing gear that conform with the annual biophysical actualities and ecological dynamics of the Mekong River. These learned efforts allow them to maintain their sustainable family livelihoods. If the free-flowing Mekong River is turned into a series of interconnected reservoirs, many of these diverse (sub) ecosystems would be lost. Fishermen could no longer rely on their traditional fishing gear and their effective transferred indigenous knowledge to sustain their families' livelihoods. Promotion of reservoir fisheries will be least beneficial to these affected communities because of the lack of knowledge to practice fishing effectively in such a vastly different biophysical environment under entirely different ecological conditions. Inter- and intrageneration networking and insight would be lost without proper management (Mekong-Lanna Natural Resources and Culture Conservation Network 2009).

k) A key adaptability issue to consider is how resilient and adaptive Mekong people are and, specifically, how likely it is that they can move from their traditional lowland floodplain areas into other areas of the basin.

Research and experience from within the region suggest that such a move would be tremendously disruptive and, for most of these individuals, highly unlikely (Gajaseni 2006). Their traditional livelihood practices of seasonal paddy rice cultivation passed down from generation to generation combined with fishing using highly diverse fishing gear reflecting accumulated indigenous knowledge would undergo a massive transformation. In their place, people would need to develop the capacity to engage successfully in upland rice cultivation techniques or slash and burn agriculture accompanied by hunting and gathering in nearby forests. Household economies that depend on paddy rice and riverbank garden vegetables for nutrition and on capture fisheries for protein will be forced to change into new and uncertain survival tactics, based on very little applicable indigenous knowledge. For nearly all of them, their new household economic situation is likely to be negative rather than positive when compared to their present conditions.

2. Recommendations for Future Social Impact Assessments in Mekong Water Resources Planning

Based on the discussion above, key recommendations on the application of alternative methodologies and analytical approaches to enhance future social impacts assessments are offered for future basin-wide planning processes in the LMB.

Stakeholder coverage

- A full range of vulnerable resource user groups should be included in future social impact assessment strategies.

- Assessment of the differential impacts of planned projects on vulnerable groups (low income, disadvantaged, women, etc.) should be included in future.

Social assessment and ecosystem services coverage

- Sensitivity analysis should be improved to cover more variables of uncertainty. Variables should be specifically included for each geographical, political, and cultural boundary under analysis.
- There should be a study of baseline data on natural and man-made capital in the basin, employing different methods of sampling and collection, including one that addresses the linkage between ecosystem services and social impact. This information will be useful to inform the formulation of effective mitigation, replacement, and compensation programs. Evaluation and monitoring processes should be put in place for different stages of the project development to follow the impact of the project on social and ecosystem services to avoid risks and unexpected secondary impacts.
- Ecosystem health and integrity and linkages between the cultural services of the Mekong River, local livelihoods, social integrity, value and cultural identity should be addressed in social impact assessments. These issues should be dealt with at the start of the project.
- Cumulative and transboundary impacts are recommended to be included as an integral part of impact assessment, both for EIA and Social Impact Assessment (SIA) studies.
- Maintenance of "minimum environmental flow" should be negotiated and agreed upon by all stakeholders.

Best practices

International criteria and standards for evaluating the social impacts and effectiveness of mitigation measures should be adopted in the analysis of major projects in the Mekong, including mainstream and tributary dams. Best practice evaluations should cover all impacts that could result from the project and should estimate acceptable mitigation and compensation measures for key losses, such as fisheries and rice production.