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ORIGINAL ARTICLE

Hydropower development in the lower Mekong basin: alternative approaches to deal with uncertainty

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Abstract Governments in the Lower Mekong Basin (LMB) face decisions that involve trade-offs between 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 a means of comparing these trade-offs, a sensitivity analysis of the benefit-cost analysis of certain Basin Development Plan (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 a positive $33 billion to negative $274 billion. This report recommends when dealing with large-scale, complex projects: a more comprehensive, integrated human and natural systems framework and adaptive management approach to LMB planning and development that deals with the entire watershed; a more comprehensive analysis and treatment of risk and uncertainty; a more thorough assessment of the value of direct and indirect ecosystem services; a broader set of scenarios that embody alternative models of development, broader stakeholder participation; and better treatment of the effects of infrastructure construction on local cultures and the poor.

Keywords Mekong River Basin · Sensitivity analysis · Benefit-cost analysis · Ecosystem services · Valuation · Fisheries · Wetlands · Aquaculture · Discount rate

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Introduction

Governments in the Lower Mekong Basin (LMB) face critical decisions about the future of the mainstream Mekong River. These decisions 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. Specifically, the MRC seeks to promote and coordinate sustainable management and development of the water and other related resources of the Mekong Basin, for the countries' mutual benefit and the people's sustainable 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 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 paper, 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.

This study provides a sensitivity analysis of the benefit-cost (B–C) analysis of certain scenarios developed in the BDP2 and suggests alternative planning approaches to improve the process going forward. By modifying certain assumptions and parameters within the B–C scenarios, a range of results that bracket the reasonable boundaries were developed. This provides a range of possible results, and the assumptions on which they are based in order to better inform the decision process. The primary parameters that were altered in this study to determine their sensitivity included the discount rate on natural capital, fishery yields, values of the lost fisheries, values of wetlands lost, and the ability of aquaculture to replace lost capture fisheries. This analysis showed that reasonable changes in the assumptions create a significant range in the resulting Net Present Value (NPV) of the scenarios. Based on this, we recommend alternatives to conventional B–C analysis that can better incorporate uncertainty, stakeholder participation, and integrated regional systems science.

Scenario analysis

The aim of the BDP scenario process 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, 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 on the MRC web site (http://www.mrcmekong.org/).

This analysis used three main scenarios as case studies: (i) *Definite Future Scenario* (*DF*): 2015-Upper Mekong dams plus 26 additional hydropower dams in LMB and 2008 irrigation and flood measures; (ii) *LMB 20-Year Plan Scenario with 6 mainstream dams in Northern Lao PDR*: 2015 Definite Future plus 6 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 17-cm sea level rise (hereafter referred to as the "six dams" scenario) and (iii) *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 17-cm 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 2010). 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 paper.

Risk, uncertainty, and intergenerational issues

Background

Dealing with risk and uncertainty is a key issue in any decision-making process. In the Mekong, several plans put forward 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 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 future.

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 (i.e., 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 as follows:

$$\mathrm{NPV} = \sum_{t=0}^{\infty} \mathrm{V}_r \mathrm{W}_r \quad (1)$$

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.

$$W_r = \left(\frac{1}{1+r}\right)^r \quad (2)$$

Note that for a 0 % discount rate, the value of Eq. 1 would be infinite, so one needs to put a time limit on the summation. A 0 % 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, p. 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 %. 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, p 139):

$$\mathrm{W}_t = d^t + \frac{d \times d^{t-1} \times t}{\mathrm{G}} \quad (3)$$

where

$$d = \frac{1}{1 + r} \quad (4)$$

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 %, the NPV's are 5 times as much, while at 3 % 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 % discount rate, declining to approximately 0 % 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, 3, and 1 % 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 % 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 % 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.

Valuation of changes in ecosystem services

Valuation methodologies

Many ecosystem services described above are either public goods or common pool resources. Many of these are non-excludable 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 non-rival. Many "regulatory" ecosystem services, such as flood regulation, are public goods that are both non-excludable and non-rival (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 paper, 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 paper 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 non-market 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).

Ecosystem service values of the Mekong basin

In this paper, data from the BDP2 studies were used to calculate the cost of replacing capture fisheries lost in the

Table 1 The NPV of capture fisheries lost at various discount rates with a specified replacement cost for a kilogram of fish

Country	Fisheries production (Mtons/year)	Fisheries change (Mtons/year)	Replacement $/kg	NPV @ replacement cost ($r = 0.1$) ($millions)	NPV @ replacement cost ($r = 0.03$) ($millions)	NPV @ replacement cost ($r = 0.01$) ($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

definite future scenario,[1] "6 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 2010).

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 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

[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 6 mainstream dams in Northern Lao PDR:* 2015 Definite Future plus 6 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 17 cm 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 17 cm 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.

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 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 un-priced 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 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.

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

Similar calculations were done on reservoir fisheries and aquaculture. 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 % of the protein intake, there is still substantial malnutrition in poor communities in the LMB.

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 esthetics. 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 paper, three different types of wetlands were valued: flooded forests, marshes, and inundated grassland. 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 2010). 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 with the Mississippi and the LMB. The Mississippi study found that flooded forests were valued at approximately $3,353 per hectare per year (ha/year), marshes at $3,305/ha/year, and inundated grassland at $2,332/ha/year. 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 % discount rate, depending on the scenario. On the other end of the sensitivity spectrum, a 1 % 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.

Total value of ecosystem services

Table 2 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

[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.

Table 2 Sensitivity of the total Net Present Value (NPV) to changing assumptions in each scenario from the 2000 baseline by sector and country

	Revised NPV @ replacement cost (r = Net Present Value 0.1) original BDP2 values at ($r = 0.1$) ($ millions)			Revised NPV @ replacement cost ($r = 0.03$) original BDP2 values at ($r = 0.1$) ($millions)			Revised NPV @ replacement cost ($r = 0.01$) original BDP2 values at ($r = 0.1$) ($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)	*$66*	*$97*	*$920*	*$221*	*$323*	*$3,066*	*$663*	*$970*	*$9,198*
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)	*−$1,034*	*−$1,811*	*−$6,436*	*−$3,445*	*−$6,038*	*−$21,453*	*−$10,335*	*−$18,114*	*−$64,360*
Wetland area reduction (original)	−$228	−$178	$101	−$228	−$178	$101	−$228	−$178	$101
Wetland area reduction (revised)	*−$1*	*−$5*	*−$1*	*−$5*	*−$16*	*−$3*	*−$14*	*−$47*	*−$10*
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

Table 2 continued

	Revised NPV @ replacement cost (r = Net Present Value 0.1) original BDP2 values at ($r = 0.1$) ($ millions)			Revised NPV @ replacement cost ($r = 0.03$) original BDP2 values at ($r = 0.1$) ($millions)			Revised NPV @ replacement cost ($r = 0.01$) original BDP2 values at ($r = 0.1$) ($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)
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)	$11,159	$25,601	$32,254	$8,899	$21,589	$19,381	$2,441	$10,128	−$17,400
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*

Italicized rows are with alternative assumptions on the value of capture and reservoir fisheries, aquaculture, and wetland ecosystem services

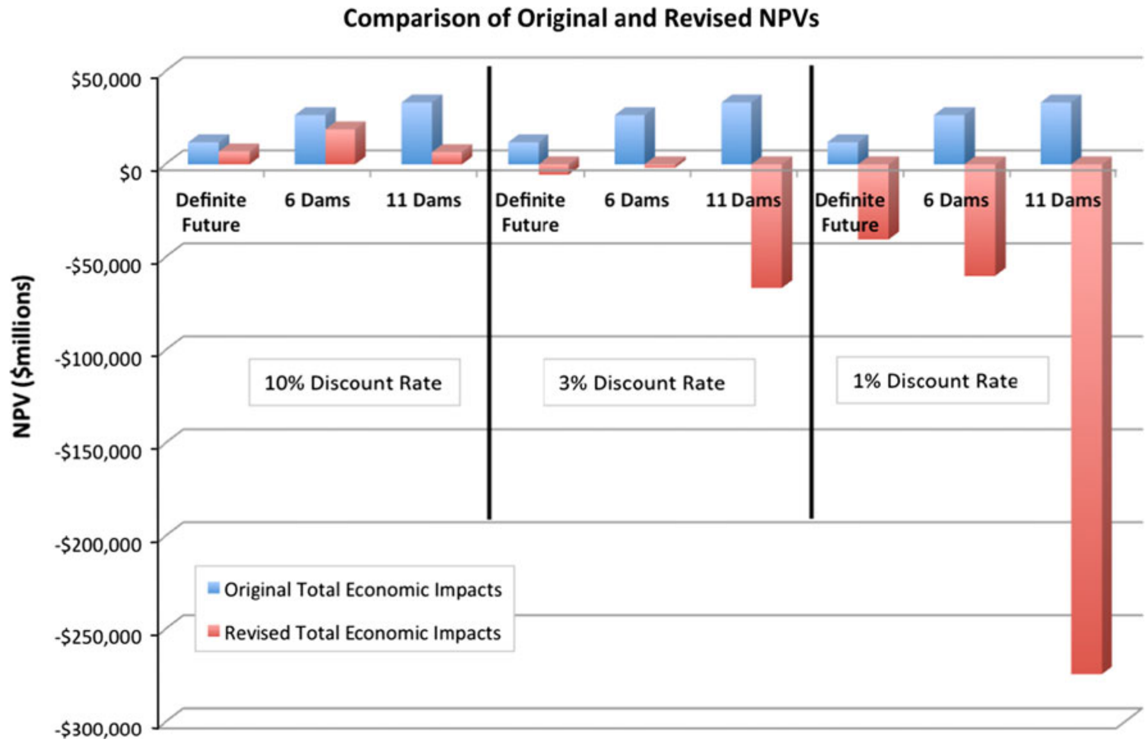

Fig. 1 Comparison of original and revised NPVs for the three scenarios assuming 10, 3, and 1 % discount rates under the sensitivity analysis

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 % of capture fisheries loss. The discount rates for aquaculture were not changed (10 % 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 % discount rate in the definite future, it 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 % 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 % discount rate, the overall NPV for the maximum development scenario would change from positive $33 billion to negative $274 billion. Figure 1 compares original and revised NPVs for the three scenarios under this sensitivity analysis.

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 % 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 % 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.

Conclusions and recommendations

BDP scenarios are formulated to evaluate the 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, provided a basis for discussion and negotiation of mutually beneficial levels of water resource 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 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

Table 3 Basic characteristics of the current development model and the emerging ecological development model (from Costanza 2008)

	Current development model: the "Washington Consensus"	Ecological 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 must shift from merely growth to "development" in the real 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 similar)
Scale/carrying capacity	Not an issue since markets are assumed to be able to 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 very real senses is often exacerbated by growth: a too rapidly rising tide only lifts yachts, while swamping small boats
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 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	*Lasse faire* market capitalism	Lisbon principles of sustainable governance

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 (Table 3).

Knowledge of ecosystems and human systems is incomplete; these systems are dynamic and difficult to predict changes that 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 a more "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 capitals are 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 paper explored a broader sensitivity analysis to

Table 4 Alternative policy assumptions versus future state of the world for LMB development choices

	Future state	
	If optimistic assumptions correct	If precautionary assumptions correct
Policy choices	Lost capture fisheries very important to local populations and not fully replaceable with aquaculture	Lost capture fisheries and related livelihoods and cultures can be replaced (i.e., with aquaculture)
	10 % discount rate is appropriate for all capital (including natural)	1 % discount rate for natural capital (10% for aquaculture)
	distribution and cultural issues are not extremely important	distribution and cultural issues very important
	no viable energy alternative to large hydropower	small scale hydro, wind and solar energy are viable energy options
	other risks are negligible	other risks [i.e., earthquakes] are significant
Optimistic	1. Optimistic future	2. Negative net benefits
Rapid economic growth is the primary mode of increasing well-being via hydropower, water supply, irrigation, and flood protection.	Positive net benefits; rapid economic growth outweighing negative social and environmental outcomes	Large decrease in well-being of local populations. Risk of catastrophic losses. Environment permanently damaged.
Precautionary	3. Economic growth slowed and delayed, but local populations and fisheries maintained. Burden of proof shifted to dam developers	4. Long-term human well-being enhanced, even though conventional economic growth slowed
More broadly defined sustainable human well-being is the primary goal. Construction pause until uncertainty resolved (SEA precautionary approach)		
Evaluation of broader range of alternatives,		
Require assurance bonds		

deal with parameter uncertainty around discounting, the value of fish, and the value of wetlands. 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, policy-makers could require hydropower developers to 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. The developers would have the option, of course, to develop sediment by-pass 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 4 is one way to summarize the major uncertainties involved in LMB planning. It shows on the left two major policy positions—optimistic about parameters and models versus 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 #2 are net positive by varying degrees. From an adaptive management perspective, given the significant uncertainty about the real state of the world, policy-makers 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 4, 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. 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 (Wilkenson 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 could 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. As one potential solution, policy-makers can 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. Something similar 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 idea of "scenario planning" could be more fully employed to develop a much broader range of scenarios that embody alternative models and trade-offs 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 trade-offs involved.

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