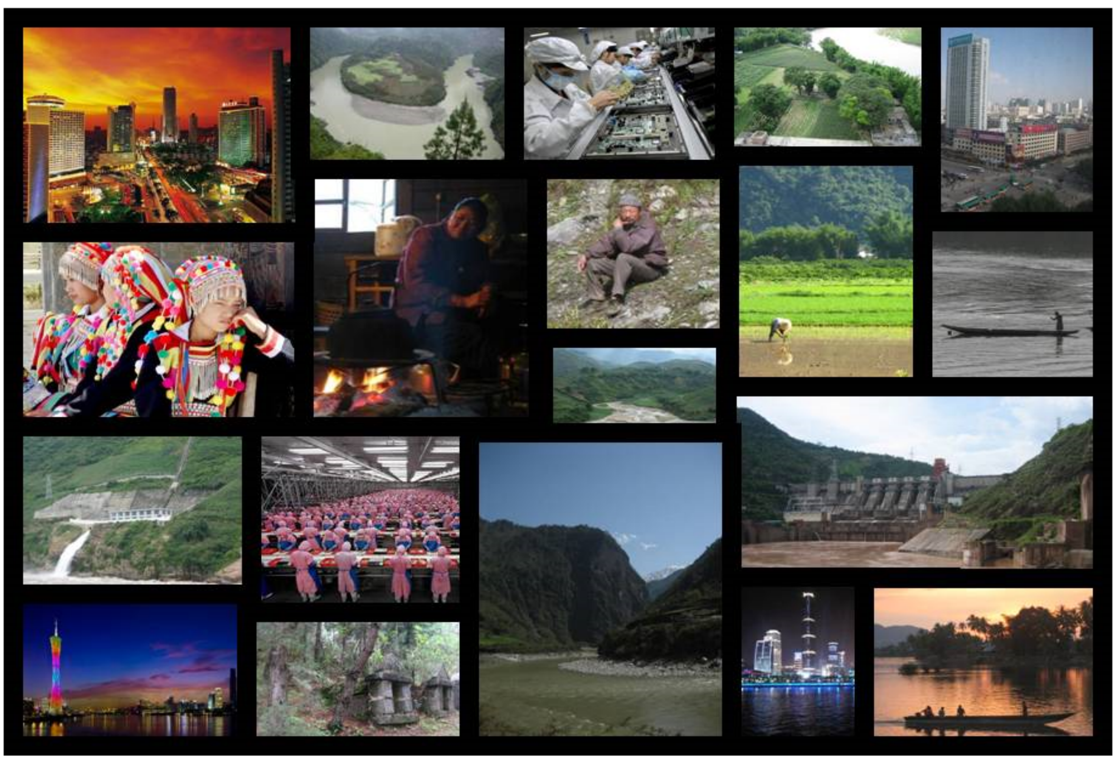
Integrative Dam Assessment Model (IDAM) Documentation

A Users Guide to the IDAM Methodology and a Case Study from Southwestern China



OSU Oregon State University

IDAM Integrative Dam Assessment Modelling

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HOBART AND WILLIAM SMITH COLLEGES

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EXECUTIVE SUMMARY

Outcomes of the World Commission on Dams landmark analysis emphasize the role of decision making with regard to large dam development, declaring the need for more transparent and participatory processes that adequately avoid, minimize, and compensate for unintended consequences. One of the foremost challenges therein is the need to broaden discussions of dam impacts to include social and environmental consequences, acknowledging that effects may transcend traditional disciplinary boundaries. Supporting this direction, the Integrative Dam Assessment Model (IDAM) is a research and data visualization tool, allowing stakeholders and decision makers to query and observe dam costs and benefits across socioeconomic, geopolitical, and biophysical systems.

The IDAM method:

- facilitates multidisciplinary study of dam impacts, uniting information about effects to socioeconomic, geopolitical and biophysical systems;
- uses quantitative methods to illustrate objective measures of the ***magnitude*** of dam effects;
- is a participatory process; objective impact magnitudes are tempered by subjective valuation of the ***salience*** of these effects by relevant project stakeholders.

Combining impacts into one collaborative, holistic analysis, with emphasis to synergistic relationships among socioeconomic, geopolitical and biophysical systems, IDAM exceeds capabilities of discrete disciplinary evaluations that often inform dam decision making. By providing visual representation of costs and benefits associated with two or more dams, or various operations scenarios, the IDAM tool allows decision makers to evaluate alternatives and to articulate priorities associated with dam projects, making decision processes more informed and more transparent. For these reasons, we believe that the IDAM tool represents an important evolutionary step in dam evaluation.

1.0 USERS GUIDE TO THE IDAM METHODOLOGY

1.1 BACKGROUND: DAM BUILDING AND DECISION MAKING

Dams have contributed to human development by providing reliable water and energy resources, among other important benefits. As climates change, the extent and number of areas affected by severe drought and those subject to high vulnerability from flooding due to heavy precipitation will likely increase in coming decades (IPCC, 2007). Dams may play an increasingly important role in adapting water supplies, agriculture, and infrastructure to a changing climate. Thus, while large dam building slowed in the second half of the 20^{th} century (WCD, 2000), the next generation will likely witness renewed intensity in large dam development as new dams are planned and constructed, particularly in the developing world.

1.1.1 Findings from the World Commission on Dams

After undertaking a comprehensive, global assessment of dams, the World Commission on Dams (WCD) report that large dams have often enacted unintended and largely undocumented and unmitigated consequences to the physical environment and to social systems. WCD declares the need for more equitable and sustainable decision making with respect to large dams, and emphasizes that new models of decision making must involve key stakeholders throughout the process. Much subsequent research also advocates improving decision-making processes regarding large dams (McCully 2001. Mokorosi and van der Zaag 2007, Koch 2002, Dingwerth 2005). However, important challenges in implementation remain unresolved. Chief among these is how best to carry out equitable and sustainable decision making in situations where information is scarce, or in which there exists strong institutional resistance to WCD recommendations. Specifically, WCD recommendations to open assessment procedures to public scrutiny or comment are often contentious (Dubash et al. 2002). To move water resources development in the direction of improved dialogue and greater transparency, a number of approaches are under development to enhance water governance and decision making (WCD 2000, van der Zaag et al. 2009, Turner et al. 2003, Simonovic and Fahmy 1999).

1.1.2 Interaction of socioeconomic, geopolitical, and biophysical dam effects

One of the foremost challenges to improving dam decision making is the need to broaden discussions of dam impacts to include effects that are often difficult to quantify or foresee, and to foster discourse exploring ways that these effects may transcend traditional disciplinary boundaries. Documented unintended consequences of large dams offer insight to potential risks associated with dam construction, as well as the potential for lessening impacts by considering integrative impacts across disciplines. Adverse ecological effects of dams affecting hydrology, and water quality (e.g., Petts 1984, Poff et al. 1997, Poff and Hart 2002, Ward and Stanford 1979) often affect society by disrupting existing cultural and economic institutions (Goldsmith and Hilyard 1986, Cernea 1999, Scudder 2005) and by influencing relationships between the dam community and communities both up- and downstream, which may include people in other political jurisdictions. Dams have displaced up to 80 million people worldwide (WCD, 2000), resulting in increased landlessness and unemployment in addition to social disarticulation (Cernea 1999). Relocation efforts associated with dam building often lead to higher population densities and loss of arable land, and thus to greater struggles over land access (Webber and McDonald, 2004).

Social tensions and conflict are associated with environmental scarcity and unequal distributions of natural resources (Anderson et al. 1996; Ayling and Kelly 1997; Dalby 2002; Homer-Dixon 1994; Homer-Dixon 1999; Rønnfeldt 1997). Conflicts as mild as frustration among members of a community (Kant and Cooke, 1999) or as severe as violence over resource ownership rights and responsibilities (Suliman, 1999) will likely become more common with increasing population and resource demands (Buckles, 1999). In the case of dam development, these conflicts occur in part because the costs may be experienced differently by communities geographically and culturally tied to the river relative to those who access its resources remotely. Given the extensive spatial context of hydropower development, conflicts over damming rivers have the potential to extend over numerous levels of organization, and this complex interplay of drivers and responses results in several basic yet critical questions regarding the sustainability of hydropower.

These undesirable outcomes are often either irreversible or difficult to reverse (Whitelaw and MacMullan 2002), and the negative impacts of environmental change associated with dams tend to fall disproportionately on vulnerable populations based on racial, ethnic, gender, and economic status (Bocking, 1998). Moreover, the costs and benefits of dam construction often accrue differently to different stakeholders (Bocking 1998). Thus, while it is clear that dams provide many benefits to society, it is also clear that dam impact evaluations undertaken through different disciplinary perspectives may lead to vastly different conclusions about the relative costs and benefits of a given project.

1.1.3 Need for more comprehensive decision-making models

The 1992 United Nations Conference on Environment and Development identified socioeconomics, geopolitics, and biophysics as primary areas of concern for environmental and social sustainability in development (UNCED 1993). Despite recognition that dam impacts are felt across these three areas, few studies have comprehensively evaluated the distribution of socioeconomic, geopolitical, and biophysical costs and benefits of new dam construction (Whitelaw and MacMullan 2002). Rather, most existing studies examine the impacts of dams from the perspective of a single discipline, often from either a natural science or a social science perspective. While such research yields vital insights into dam valuation, it may inadvertently miss important synergistic relationships between socioeconomics, geopolitics, and biophysics. History indicates that the reductionist, discipline-based approaches of the past have not sufficiently documented the interconnected nature of socioeconomic, geopolitical, and biophysical drivers and outcomes of dams.

To meet simultaneous demands for water, energy, and environmental protection well into the future, a broader view of dams in the context of long-term sustainability is needed. Specifically, collaborative, holistic approaches to study integrated effects of dams are necessary, with emphasis to how synergistic relationships among socioeconomic, geopolitical and biophysical realms impact river communities. Addressing this need, we have developed an integrated, multidisciplinary approach to evaluating dam impacts. The Integrative Dam Assessment Model (IDAM) framework seeks to fulfill the WCD's recommendations for the equitable and sustainable development of water resources, facilitating comprehensive options assessments that equally consider the socioeconomic, geopolitical and biophysical components of alternative development scenarios. The IDAM model further embodies WCD recommendations by formally integrating stakeholder participation as a foundation of the decision-making process. Moreover, by documenting information used in evaluating dam development alternatives, the IDAM framework encourages transparency in decision making. The contributions of this work include an integrative, multidisciplinary tool to support decision making in the face of risks and uncertainties by more completely representing the risks and rewards of hydropower development.

1.2 THE INTEGRATIVE DAM ASSESSMENT MODEL (IDAM)

1.2.1 Conceptual design of IDAM

IDAM proposes a novel method for considering benefits and costs of dams in a framework that integrates multiple spheres over which dam impacts may occur. Drawing from the 1993 United Nations definition of sustainability in development as three equivalent pillars of socioeconomics, geopolitics, and biophysics (UNCED, 1993; Figure 1.1), the IDAM tool provides a common space where these three disciplines may be simultaneously accounted and compared, uniting information traditionally available to decision makers only in discrete disciplinary analyses (e.g. Social Impact Assessment, Benefit-Cost Analysis, Environmental Impact Assessment).

Figure 1.1: Three pillars of social and environmental sustainability.

Conceptually, the IDAM model evaluates two aspects of dam impacts: 1) objective measures of the ***magnitude*** of dam effects, and 2) subjective valuation of the ***salience*** of effects by relevant project stakeholders. For example, the magnitude of a dam's installed capacity may convey information regarding the magnitude of effect to energy supplies. However, salience conveys how important this impact is to people affected by the project and allows the inclusion of nuanced, value-based information that isn't captured by the objective magnitude of impact. One may imagine a scenario in which an impact has a great magnitude, yet salience data indicate that project stakeholders assign little importance to this impact. Or, conversely, impacts of seemingly insignificant magnitude may be highly valued by stakeholders.

Implementation of the IDAM framework proceeds according to the following process:

Step 1: Quantifying impact magnitudes

To illustrate potential impacts or vulnerabilities across socioeconomic, geopolitical, and biophysical systems, a suite of objective, quantitative impact magnitudes, or ***indicators*** of impact, is presented for each discipline.

Step 2: Collection of salience information from project stakeholders

Beside each indicator magnitude, corresponding information on the salience of the impact, collected from a group of stakeholders, is presented.

Step 3: Data visualization and discourse

IDAM visualization tools convey both the magnitude and salience of dam impacts across socioeconomic, geopolitical, and biophysical systems, allowing decision makers to identify priority issues associated with an individual dam, or to compare distributions of impact for two or more dams or management options. In this way, the IDAM framework makes both magnitudes of dam impacts and individual salience, or how we value or care about a particular impact, explicit and transparent. This process simultaneously facilitates discussion among decision makers, highlights fundamental differences between groups of stakeholders, and documents the information that was used to reach a decision.

1.2.2 IDAM impacts and indicators

Information relevant to dam decision making is often specific to individual dams or river systems, thus data necessary to inform decision-making processes may differ among potential scenarios. For this reason, the IDAM tool offers maximum flexibility to users in determining relevant and available information to be included in evaluations. However, deciding which dam impacts to consider and how to evaluate magnitudes of these effects can be a difficult task. The metrics selected may greatly affect model outcomes, thus we recommend that careful consideration is given to selection of metrics. In developing and testing the IDAM model, we spent considerable time and resources compiling a suite of metrics that comprehensively, yet simply describe potential dam impacts. We offer our selected metrics (Tables 1.1-1.3) and the process that we have undertaken to arrive at this assemblage as suggestions for information to include, or methods to apply in determining appropriate metrics.

The suggested impacts included in the IDAM tool are informed by an extensive review of the existing literature, including evaluations of environmental effects (e.g., Bunn and

Arthington 2002, Goldsmith and Hildyard 1986, McAllister et al. 2000, Rosenberg et al. 2000, WCD 2000), social effects (e.g., Bartolome et al. 2000, Egre and Senecal 2003, Lerer and Scudder1999, Sadler et al. 2000, Scudder 1997), and the geopolitics (e.g., Bakker 1999, McCully 2001, Ribeiro 1994, Scudder 2005, Waterbury 1979) of large dams. Following this initial literature review, groups of experts with experience evaluating dam impacts gathered for structured discussions regarding the specific impacts to be included and to deliberate potential indicators that describe magnitudes of these impacts. These discussions were facilitated using the Delphi Technique (Gordon and Helmer, 1964), a method enabling interdisciplinary dialog among experts to develop consensus on the key components for analysis and providing process techniques to resolve differences as they arise. The Delphi Technique has proven effective in facilitating water resource planning (Meedham and de Loe 1990). Linstone and Turoff (1975) and Rowe and Wright (1999) provide thorough summaries of the strengths and weaknesses of the methodology. We conducted these discussions during international symposia and after three such consultations with expert focal groups, had reached consensus regarding the resultant dam impacts included in the model.

Although we do not intend that our chosen suite of metrics (Tables 1.1-1.3) or approaches to evaluation are the definitive impacts and indicators relevant to all dam decision scenarios, considering the potential for selected impacts and methods of evaluation to influence model outcomes, we do suggest that users conduct no less thorough of a review and consultation with expert groups when selecting dam impacts and indicators.

1.2.2.1 Evaluating indicators of impact magnitude

We asked that experts consider how any one impact may be evaluated as both a benefit and a cost to the system, or as a positive and negative impact (see Tables 1.1-1.3). For example, in evaluating changes to income arising from a new dam, researchers may discover that new jobs brought by the dam increase wages, creating an income benefit, while inundation of agricultural land may decrease incomes of farmers. However, both positive and negative valuations of an impact may not apply to all dams, and it is possible for either benefit or cost magnitudes associated with an impact to be zero.

Additionally, in formulating methods for evaluating dam impacts, we asked experts to reflect upon sources of information that are generally available to decision makers before a dam is built and to design indicators that may be evaluated using available information, even in data-poor scenarios. Balancing competing needs of comprehensive information and simplicity, the suggested metrics are designed to be useful even in situations where detailed information is unavailable.

1.2.2.2 Subindicators

Often, two or more discrete pieces of information are combined to evaluate one dam impact. For example, watershed-scale effects to sediment transport are evaluated as a combination of dam siting within the basin and trap efficiency of the reservoir. To create one composite impact magnitude, these two pieces of information, termed ***subindicators***, are mathematically combined to provide an index of effects to sediment transport processes. To combine subindicators with similar units, such as categorical or binary data, we calculate the mean impact across subindicators. When combining subindicators with different units, such as trap efficiency (percent) and basin area (l^2), it is necessary to nondimensionalize subindicator values before combining. We often nondimensionalize variables by comparing values to the sample, for instance, to sample maximum, mean and standard deviation (z-score), or to a cumulative distribution function (percentile). For example, to nondimensionalize with respect to sample maximum, we reference the population of dams under comparison and normalize each subindicator value by the maximum subindicator value within our population of dams, transforming each subindicator to a nondimensional value between 0 and 1. We then combined the values for each subindicator multiplicatively. See equation 1.1:

$$\text{indexed magnitude} = \frac{\text{sub}_\text{i}}{\text{maximum sub}_\text{i}} \times \frac{\text{sub}_\text{j}}{\text{maximum sub}_\text{j}} \times \frac{\text{sub}_\text{k}}{\text{maximum sub}_\text{k}} \qquad \text{Eq. 1.1}$$

Table 1.1: Socioeconomic impacts of dams and indicators of effect.

IDAM SOCIOECONOMIC IMPACTS AND INDICATORS

IMPACT NAME	POSITIVE SCOPE OF IMPACT	NEGATIVE SCOPE OF IMPACT	INDICATOR
SE1: Social Cohesion	Dams may facilitate transportation across rivers, integrating less accessible portions of communities with the rest of the community	People from one community may be resettled into multiple new communities, disrupting social cohesion	Index of community trust and cohesiveness; participation in village activities; borrowing and lending networks; labor sharing networks
SE2: Cultural Knowledge and Behavior	Dams may increase ethnic diversity and increase access to educational opportunities	Dams may decrease cultural knowledge of the local ecosystem and decrease educational opportunities	Index of impacts on ethnic composition of community; middle school enrollment rates
SE3: Material Culture	Dams may contribute to the preservation or protection of sites of cultural significance	Inundation of tombs, religious sites, and other areas of cultural significance; loss of access to importance resources	Index of impacts on material culture, including tombs and other sites of cultural significance
SE4: Infrastructure	Communities that were once isolated or that relied on small hydro or alternative forms of electricity generation may be connected to the grid; water treatment facilities may improve the quality of drinking water; dams facilitate infrastructural development	Prices of electricity may rise as the source of power may be farther away; the prevalence of water-borne diseases may increase	Index of access to roads, electricity and potable water
SE5: Income	Incomes may rise as off-farm opportunities working on dam construction arise; government transfers may stimulate local economy	Inundation of agricultural land may result in decreased incomes for farmers	Household income compared to watershed average from household surveys, community surveys

Table 1.1 (continued): Socioeconomic impacts of dams and indicators of effect.

IDAM SOCIOECONOMIC IMPACTS AND INDICATORS (continued)

IMPACT NAME	POSITIVE SCOPE OF IMPACT	NEGATIVE SCOPE OF IMPACT	INDICATOR
SE6: Wealth	The quality of housing and/or land in resettlement communities may exceed that in the affected area	Resettlers may deplete resources in resettlement communities; land and other resources in resettled communities may be inferior to affected area; resettlement compensation may be inadequate	Housing values compared to watershed average from household surveys, community surveys
SE7: Macro Impacts	New roads and other forms of infrastructure for dam development may have positive spillovers for tourism and other industries; money spent on dam construction may dramatically increase local economic activity; commercial value of hydropower contributes to national economy	Resettlement of displaced peoples may be costly	Index of the cost of resettlement, costs of infrastructure, and present commercial value of hydropower produced from community surveys, State Statistical Bureau data, and industry estimates

Table 1.2: Geopolitical impacts of dams and indicators of effect.

IDAM GEOPOLITICAL IMPACTS AND INDICATORS

IMPACT NAME	POSITIVE SCOPE OF IMPACT	NEGATIVE SCOPE OF IMPACT	INDICATOR
GP1: Domestic Shock	Dams provide three main benefits: hydropower, irrigation, and flood control	Resettlement and associated costs	Magnitude of installed electrical capacity, irrigation provided, flood control, and resettled population relative to other dams in the country
GP2: International Institutional Resilience	Treaties or river basin organizations (RBOs) that enable riparian nations to jointly manage international rivers have the potential to attenuate stress and distribute costs and benefits resulting from dam construction	Dam construction causes negative impacts (e.g. damage to fisheries, property, or livelihoods) for individuals and communities outside the immediate area of the dam	Treaty coding for specific water management capacities and people in basin
GP3: Political Complexity	As impacts cross a greater number of boundaries, and boundaries of increasing complexity, dam development creates opportunities for regional cooperation.	As impacts cross a greater number of boundaries, and boundaries of increasing complexity, dam development may lead to greater tensions among riparians.	Number and type of boundaries crossed by the river: county, national, international
GP4: Legal Framework	Strong laws help mitigate the impacts of change; existing basin agreements and associated River Basin Organizations (RBOs) help reduce vulnerability throughout basin	Laws and other institutions are weak or nonexistent, and insufficient to mitigate negative impacts or reduce vulnerability	Administrative level of highest legal framework governing dam site

Table 1.2 (continued): Geopolitical impacts of dams and indicators of effect.

IDAM GEOPOLITICAL IMPACTS AND INDICATORS

IMPACT NAME	POSITIVE SCOPE OF IMPACT	NEGATIVE SCOPE OF IMPACT	INDICATOR
GP5: Domestic Governance Transparency	Decision processes are open and transparent; governmental management capacity is robust; civil dialogue is open and active	Decisions processes are closed and obfuscated; governmental management capacity is limited; civil dialogue is limited/constrained	Democracy Index relative to countries world-wide
GP6: Domestic Political Stability	Cooperation during planning, construction, operation, and management phases leads to the establishment or strengthening of institutional arrangements and promotes improved relations among relevant administrative areas (internal)	Lack of cooperation during planning, construction, and operation, and management phases, or other conflicts related to project, increases tensions in relations among relevant administrative areas (internal)	Domestic water event intensity scale
GP7: International Political Stability	Cooperation during planning, construction, and operation, and management phases leads to the establishment or strengthening of institutional arrangements and promotes improved relations among relevant administrative areas (international)	Lack of cooperation during planning, construction, and operation, and management phases, or other conflicts related to project, increases tensions in relations among relevant administrative areas (international)	International water event intensity scale

Table 1.3: Biophysical impacts of dams and indicators of effect.

IDAM BIOPHYSICAL IMPACTS AND INDICATORS

IMPACT NAME	POSITIVE SCOPE OF IMPACT	NEGATIVE SCOPE OF IMPACT	INDICATOR
BP1: Impact Area	Reservoir may create potential habitat for rare/endemic species	Aquatic, riparian, and terrestrial habitats for endemic or rare species may be disturbed or destroyed	Indices of habitat quantity- surface area of the reservoir, length of river impounded
BP2: Habitat Diversity	Reservoir may create potential habitat for rare/endemic species	Lotic and terrestrial habitats of rare or endemic species may be destroyed; migration routes may be interrupted	Indices of habitat quality- habitat diversity of affected areas, amount of conservation land inundated, conservation area proximity index
BP3: Carbon Emission Reduction	Generation of hydropower may reduce emissions of GHG, may improve local air quality	Emissions from reservoir may offset a portion of GHG saved by hydropower production	Amount of GHG emitted from equivalent MW of coal power generation, energy density (MW/unit area of reservoir)
BP4: Landscape Stability	NA	Reservoir may induce seismicity, road construction and reservoir may increase landslide potential	Seismic potential: Depth and volume of reservoir, distance to active faults; Landslide hazard: slope, vegetation, precipitation, proximity to roads

Table 1.3 (continued): Biophysical impacts of dams and indicators of effect.

IDAM BIOPHYSICAL IMPACTS AND INDICATORS

IMPACT NAME	POSITIVE SCOPE OF IMPACT	NEGATIVE SCOPE OF IMPACT	INDICATOR
BP5: Sediment Modification	Reservoir may store anthropogenic sources of sediment, decrease turbidity and sediment aggradation downstream	Reservoir may disrupt natural longitudinal sediment movement; downstream channel and bank stabilization infrastructure may erode; downstream grain size distribution may change; depositional features (bars, islands, deltas), and channel morphology (width, depth, sinuosity) may change	Trap efficiency of dam, percentage of basin that contributes to the dam
BP6: Hydrologic Modification	Dam may reregulate altered flows (if dam is most downstream of a series of dams)	Dam may change historic hydrograph- magnitude, duration, timing, and frequency of high and low flows; may cause downstream changes to channel morphology, migration or spawning cues, substrate conditions, condition of riparian vegetation	Storage potential of reservoir: percent of annual runoff stored in reservoir
BP7: Water Quality	Reservoir may store heavy metals, pesticides, PCBs, preventing downstream contamination	Reservoir may change cycling of nutrients and carbon, decrease DO, TSS, and turbidity, alter diel and seasonal temperature patterns, affect growth of periphyton	Percent change in residence time through reservoir reach

1.2.3 Stakeholder participation

Project stakeholders play an active and vital role in the IDAM process. The IDAM tool is intended to hold a heuristic mirror up to decision makers by providing a visual representation of both the magnitude and valuation of dam impacts. The values of participating project stakeholders, as expressed in salience data, convey importance of various dam impacts to inform decision making. Therefore, to ensure a truly transparent and balanced process, selection of project participants must follow methodologies proven to create an unbiased group of stakeholders. Model users must ensure that participating stakeholders represent a true cross-section of people likely to experience effects of the proposed dam and that each group is equally represented. The group of stakeholders contributing to IDAM analysis will ideally include experts representing the broad spectrum of interests, from those trained to assess and make decisions about the impacts of dams through socioeconomic, geopolitical, and biophysical frameworks to citizens affected by decisions about the dams. We anticipate that this analysis will involve negotiation and consensus-building through a process similar to the Delphi Method, thereby improving the transparency of the decision making process.

In order to contribute information that accurately reflects their position and values, project stakeholders must fully understand the potential impacts of the proposed development projects. Additionally, outside groups evaluating the decision process must also understand how impact magnitudes were evaluated and how salience data were collected. For these reasons, documentation is an important element of IDAM methodology. Practitioners should ensure that clear, accurate, unbiased information is provided to all project stakeholders. Evaluation of each impact magnitude should be carefully documented and disseminated to participants, along with detailed descriptions of each potential impact. For example, data and equations used to evaluate indicators must be cited, and methods of data collection must be clearly outlined if IDAM practitioners developed their own data to inform impact magnitudes.

1.2.4 Data visualization

Although the IDAM process outlines and greatly streamlines information used in decision making, the information provided is nevertheless often extensive, reflecting the complexity of dam development impacts. Because relevant information may be vast and intricate, lucid presentation of data will help project stakeholders comprehend information used in determining salience of impacts, and will also allow decision makers to easily absorb the foremost conclusions. Below we suggest specific ways that IDAM data may be processed and presented in order to enhance clarity.

1.2.4.1 Nondimensional impact magnitudes

Within the IDAM tool, many indicators representing impact magnitude have dimension, or units. For example, the third geopolitical indicator (GP3, Political Complexity) is assessed by the number of political boundaries the river crosses, while some socioeconomic indicators (SE4 to SE6) measure changes to income and wealth in dollars. Various units are used to illustrate impact magnitudes, yet IDAM compares impacts across units. Such apples and oranges comparison, for instance, valuing dollars against number of boundaries crossed, is subjective and thus problematic. Therefore, we transform quantitative, continuous data into qualitative, categorical data, nondimensionalizing variables in the model, which allows comparison across indicators and disciplines (socioeconomic, geopolitical, biophysical). We nondimensionalize variables by categorizing impact magnitudes into discrete bins. Rather than presenting actual impact magnitudes to project stakeholders with the expectation that they should compare across disparate units, data appear binned into categories of No Impact, Small Impact, Moderate Impact, Large Impact.

There are several methods by which IDAM practitioners may determine breaks or thresholds in continuous data that differentiate Small from Moderate and Moderate from Large impacts. It has been our experience that different methods of categorization are appropriate for different types of data. Some data lend themselves easily to qualitative categories. For example, our fourth Geopolitical indicator (GP 4, Legal Framework) captures the highest level of administrative law governing a dam. With respect to this information, qualitative thresholds (e.g. local, state, national) are intuitive and appropriate. Each respective threshold is meaningful in an absolute sense.

Conversely, it is often appropriate to categorize quantitative data using mathematical or statistical methods. These methods often require that users define a reference population encompassing a range of small to large impacts, within which comparisons are made, and then define bins based on mathematical or statistical rules. For instance, our fifth Geopolitical indicator (GP 5, Governmental Transparency) captures degree of transparency in the government of the host country. Because this measure is meaningful only in relation to other countries, the reference population comprises sovereign nations of the world. In this case, we create a cumulative distribution function of transparency of all sovereign nations and define bins statistically using percentile thresholds. We then classify impact magnitudes of dams in question according to the following decision rules:

IF **IMPACT** ≅ zero, THEN **NO IMPACT**

IF 0 < **IMPACT** <= 33rd percentile, THEN **SMALL IMPACT**

IF 33st percentile < **IMPACT** <= 66th percentile, THEN **MODERATE IMPACT**

IF **IMPACT** > 66th percentile, THEN **LARGE IMPACT**

Percentile binning of z-score is useful when data derive from socioeconomic household surveys. To create bins based on z-score, we define a population consisting of responses from all surveyed households. We calculate z-scores according to Equation 1.3 and then apply percentile binning according to the empirical distribution of households or villages in the sample. In Eq. 1.2, individual is the mean of the displaced or to be displaced population (village), the sample mean is the mean of the entire sample (all villages), and sample stdev is the standard deviation of the entire sample (all villages).

$$\mathrm{z-score} = \frac{(\mathrm{individual} - \mathrm{sample\ mean})}{\mathrm{sample\ stdev}} \qquad \text{Eq. 1.2}$$

Finally, defining bins of equal measure is useful when populations are small, with low n such that cumulative distribution functions are not supported. We define three equal bins with reference to the maximum value within the population and classify impacts as follows:

IF **IMPACT** = zero, THEN **NO IMPACT**

IF 0 < **IMPACT** <= (max impact/3), THEN **SMALL IMPACT**

IF (max impact/3) < **IMPACT** <= (2*(max impact/3)), THEN **MODERATE IMPACT**

IF **IMPACT** > (2*(max impact/3)), THEN **LARGE IMPACT**

1.2.4.2 Visualization tools

The IDAM model is, at its core, a data visualization tool, allowing stakeholders and decision makers to observe how dams affect socioeconomic, geopolitical, and biophysical systems. By combining impacts from multiple realms into one analysis, IDAM exceeds capabilities of discrete disciplinary evaluations that often inform dam decision making. However, simultaneous consideration of many and variable dam impacts creates a complex data output that can easily overwhelm practitioners and decision makers. Furthermore, because IDAM fundamentally requires cooperation across disciplinary boundaries, and because people of different backgrounds often process and absorb information in different ways, it is critical that IDAM information is presented in such a way that practitioners of varied background may easily extract information. The primary challenge to effective presentation of IDAM data is to convey as much specific information to decision makers as possible, clearly highlighting salient features of the data while minimizing confusion.

In design of IDAM visualization tools, we consulted a computer scientist and visualization expert, and conducted surveys to assess how easily and accurately people across disciplines acquire information from figures. With the visualization expert, we developed a survey, identifying questions that tested both people's preferences and accuracy in extracting information. We implemented this survey among groups of social science, natural science, and engineering students. We first assessed demographics (e.g. gender, age, highest level of education, discipline, highest level of math, color blindness) of the survey participants and explained how to read two figure options (amoeba diagrams and color saturation bar charts). We then provided information on competing dam design alternatives as a narrative, and also summarized impact data in two figure options and as a table of numbers. To evaluate the accuracy with which students interpret different figures, we asked students to find specific information from the figures, and to interpret patterns that they see. We also asked which figure felt most comfortable and what was pleasing/displeasing about the layouts. Our survey indicated that students initially found the bar charts easy to understand, likely because most students had ample past experience reading bar charts. However, once students gained more experience with the amoeba diagram, students found the amoeba to be a more informative presentation of IDAM data than the bar charts. Regardless of figure layout, students with experience in abstractions (math) extracted information from graphical displays more accurately.

1.2.5 Model limitations and considerations for implementation

The indicators of impact suggested in Tables 1.1-1.3 balance competing needs for completeness of information, yet simplicity of data requirements. In general, the more specific information that is included in impact evaluation will lead to a more complete and accurate assessment of a dam's impact. However, there comes a limit to the return of excess data saturation, thus it is necessary to define boundaries to our analysis. This is not a unique conundrum, as location of system boundaries is a question inherent to any modeling effort. Within our final compendium of dam impacts and indicators (Tables 1.1-1.3) is an implicit statement of system boundaries, driven by our goal to create a model that is widely applicable, even in data-poor scenarios. The boundaries of analysis are necessarily malleable, fluctuating according to requirements of specific impacts. For example, in assessing socioeconomic and biophysical impacts, we evaluate mostly local effects, defining model boundaries close to the dam site. Although it is likely that socioeconomic and biophysical impacts travel downstream to affect areas that are far from the dam site, data requirements and uncertainty related to expression of downstream or tertiary impacts are often prohibitive to assessment outside of a limited local area. Conversely, as geopolitical effects by definition transcend national boundaries, we measure geopolitical impacts at the regional, national, or international scale.

Information used to evaluate IDAM indicators of impact is sometimes correlated, or colinear. For example, we evaluate changes to water retention time in the reservoir reach (BP7, Water

Quality) and sediment trap efficiency of the reservoir (BP5, Sediment Transport). Reservoir trap efficiency is directly correlated to change in water retention time, thus these two indicators of impact magnitude are colinear. Similarly, information may be duplicated in the model such that similar data informs more than one indicator of impact magnitude. For instance, costs of resettlement are evaluated twice- once in our seventh socioeconomic indicator (SE7 Macroeconomic Impact), an economic cost-benefit analysis, and again in our first geopolitical indicator (GP1, Domestic Shock) as an estimate of disturbance to the domestic hydropolitical system. Because a single dam impact may influence multiple system attributes, we justify duplication or "double counting" of data, provided that the impacts evaluated are discrete. Indeed, the ability to visualize how dam impacts affect multiple spheres is a unique strength to the IDAM approach.

The IDAM model is intended to foster transparency in decision making. If implemented correctly, according to the guidelines outlined above, the IDAM process documents information used in decision making and fosters a repeatable, transparent, and participatory decision-making process. However, as with any process that facilitates decision making, IDAM outcomes are only as sound as implementation. Without adequate documentation of data used in decision making and transparency of process, it would be possible to manipulate the IDAM tool to justify a premade decision. For that reason, decision makers and stakeholders must have absolute access to all data on potential impacts and IDAM practitioners must carefully adhere to guidelines for correct implementation of the IDAM tool. Practical details concerning model implementation may vastly influence outcome of the IDAM process, therefore, clear communication between project stakeholders and practitioners implementing the IDAM tool is imperative.

2.0 IDAM IN PRACTICE: A CASE STUDY FROM SOUTHWESTERN CHINA

2.1 DAMS OF THE LANCANG (UPPER MEKONG) AND NU (SALWEEN) RIVERS

We illustrate application of the IDAM framework in the following case study of proposed and existing hydropower dams on two international rivers in Yunnan Province, China. The Nu (Salween) and Lancang (Mekong) Rivers both arise on the Qinghai-Tibetan plateau of western China and flow through Yunnan Province before crossing international boundaries into Myanmar (Burma) and Laos, respectively. The following analysis of Chinese Lancang and Nu River mainstem dams is an example of how the IDAM tool may be used to inform such research questions as:

- How will proposed mainstem dams affect socioeconomic, geopolitical, and biophysical systems in the Salween River basin, and how do these effects compare to those projected and observed on the Mekong River, in terms of impact magnitude and stakeholder salience? Specifically, how does regional physical and social geography influence impact magnitudes?

- To what degree are socioeconomic, geopolitical, and biophysical systems of the Nu River vulnerable to mainstem hydropower development?

- How does stakeholder salience vary across sectors (academia, industry, government, social and environmental NGOs) and disciplines (physical, social, political sciences)?

For our case study, we have selected eight existing and proposed dams for detailed analysis; four on the mainstem of the Lancang River and four on the mainstem of the Nu River (Figure 2.1). See Table 2.1 for details of dams analyzed in this study.

Figure 2.1: Study dams of the Nu and Lancang Rivers

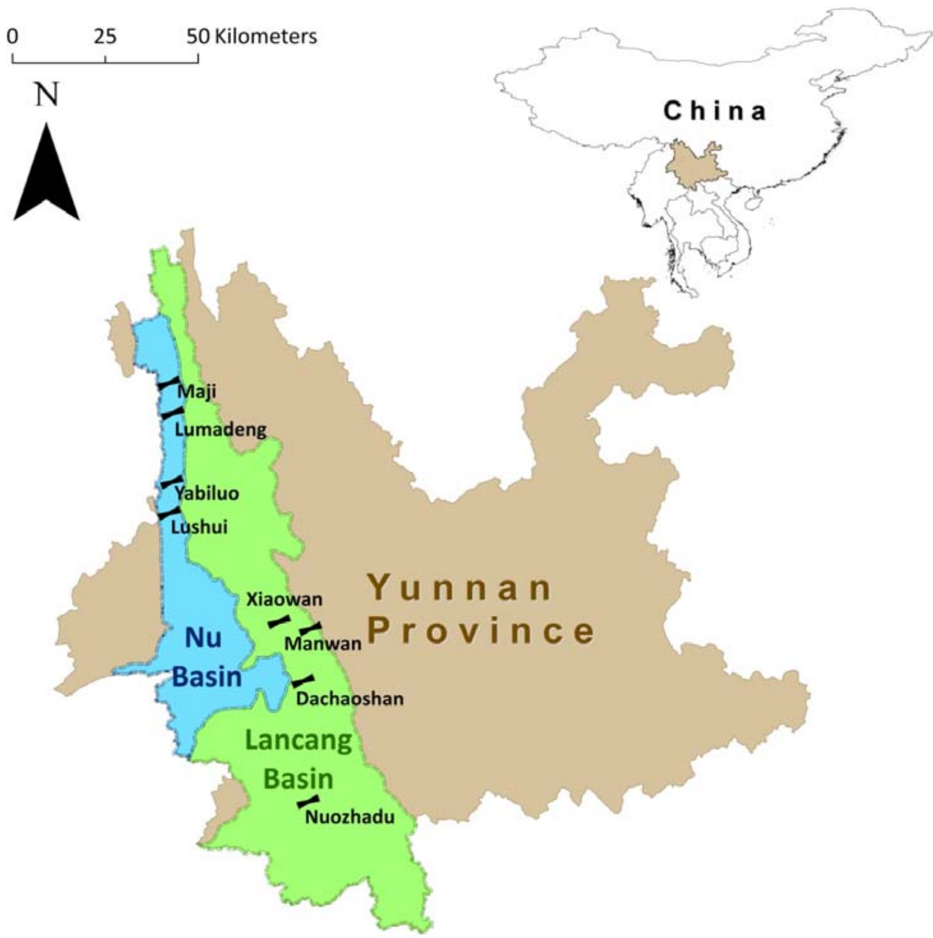


Table 2.1. Hydraulic and socioeconomic characteristics of the Nu and Lancang River study projects.

River Basin	Dam Site	Dam Height (m)[1]	Installed Capacity (MW)[1]	Reservoir Area Modeled or Observed[2] (Reported)[1] (km^2)	People displaced[3] (number)
Lancang River	Xiaowan	300	4200	93 – 195 (37)	32,737
	Manwan	126	1500	24 – 27 (4)	3,513
	Dachaoshan	110	1350	19 – 33 (8)	6,100
	Nuozhadu	254	5500	161 – 310 (45)	23,826
Nu River	Maji	300	4200	28 – 66 (17)	19,830
	Lumadeng	165	2000	3 – 11 (4)	6,092
	Yabiluo	133	1800	5 – 9 (2)	3,982
	Lushui	175	2400	8 – 19 (4)	6,190

1 Nu River dams: Dore and Yu, 2004; Lancang River dams: Plinston and He, 1999

2 Manwan and Dachaoshan observed; others modeled; Kibler, 2012 (this report)

3 Lancang dams: Magee and McDonald 2009; He et al. 2007: 147-148; Nu dams: Dore and Yu, 2004.

*As the biophysical data suggest, there is considerable uncertainty about reservoir sizes, which could affect the figures for displaced population.

2.2 STUDY SITE

2.2.1 Lancang River Basin

The Lancang (upper Mekong) River has its source in Qinghai's Yushu Tibetan Nationality Autonomous County, over 5500 m above sea level in the Qinghai-Tibet Plateau. It then flows roughly 2400 km through Qinghai, Tibet, and Yunnan before leaving China and winding its way through portions of Myanmar, Thailand, Cambodia, Laos, and Vietnam. Half of the river's length lies within China. The Lancang River basin ranges from arctic to tropical, encompassing glacial, riverine, and lentic environments. Within Yunnan, the Lancang basin is home to approximately 5 million people, many of whom are members of ethnic minority groups who have yet to see many of the benefits of the rapid economic development witnessed by China in recent years.

The Lancang River drops 1780 m as it flows through Yunnan Province, which has long attracted the attention of China's hydropower planners keen to develop some of the 25 GW of theoretical capacity (100 TWh annual output) on that stretch of the river. However, the remote location, distance from load centers, and challenging terrain have delayed detailed planning and implementation of hydropower development to recent decades. Of a proposed cascade of seven dams, Xiaowan, Manwan, Dachaoshan, and Jinghong are either complete or very near completion, while the remaining three are expected to be completed within the next decade. Two of th Lancang dams, Xiaowan and Nuozhadu, are among the world's tallest arch dam structures and create very large reservoirs, inundating vast tracts of land (Magee, 2006). From the proposed cascade of seven dams, we have selected four dams, Xiaowan, Manwan, Dachaoshan, and Nuozhadu, for detailed study.

2.2.2 Nu River Basin

The Nu (upper Salween) River is one of the most remote and least developed rivers in China. The river's name in Chinese means "angry," which may be attributed to the steep route it takes from its headwaters at 4840 m above sea level in the Qinghai-Tibet Plateau to its mouth at the Andaman Sea off southern Myanmar. On the way, the Nu traverses some 2000 km in Tibet and Yunnan before winding its way through Myanmar for another 800 km, where it briefly forms the border between Myanmar and Thailand. Over its 621-km course in Yunnan, the river drops 1116 m, yielding a theoretical hydropower capacity of some 21 GW (roughly 103 TWh annual output).

The Nu is a watershed of superlatives. In addition to being one of the most remote, it is also one of the deepest gorges on the planet, home to some of China's richest cultural and biological diversity, and the site of some of the province's and the country's poorest areas. Even more remote than the Lancang, the Nu has yet to see large-scale development of its hydropower, in part due to concern that such development would impinge upon internationally recognized sites of cultural and biological importance. In March 2004, the projects were officially halted by Premier Wen Jiabao, allegedly for failure to comply with environmental impact assessment reporting requirements. While none of the 13 projects planned for the Nu has yet been officially approved, preliminary work, including construction of resettlement villages and relocation of villagers away from planned reservoir sites, is underway. Of the thirteen dams proposed for the Chinese Nu River, we have selected four dams, Maji, Lumadeng, Yabiluo, and Lushui, for detailed study.

Application of IDAM to dams of the Nu and Lancang Rivers is challenging because hydropower development in these two international basins is an extremely sensitive research topic, all but off-limits for foreign and often Chinese researchers alike. The heightened sensitivity surrounding the Nu and Lancang dams, and the region as a whole make data collection and access to even the most basic information problematic. For instance, research tools such as GPS are forbidden, as is access to potential dam sites or resettlement villages and impact assessment reports. This challenging area is an ideal place to test the performance of the IDAM tool in data-poor scenarios.

2.3 GEOPOLITICAL DATA

The ensemble of geopolitical (GP) indicators seeks to measure ***resilience of the geopolitical system*** to the construction of one or more dams. We assume that identical dams built at Site A and Site B will have different impacts due to the different contexts in which they are built, as differences in geopolitical context may mitigate or exacerbate those impacts. Given that the principal actors in geopolitics are generally considered to be nation-states, some of the indicators below have as their reference other nation-states around the world. At the same time, sub-national actors (e.g., provincial or county governments, non-governmental organizations) may also play important roles in defining the geopolitical context (e.g., in terms of stability or openness to outside influences); for this reason, other indicators refer to domestic organizations.

2.3.1 GP1: Domestic Shock

GP1 Subindicator 1: Hydropower potential; Subindicator 2: Irrigated land; Subindicator 3: Flood protection (reservoir volume)

Hydropower, irrigation, and flood protection are three benefits of large dams with potential to influence domestic output or to shock the domestic hydropolitical system. We evaluate the magnitude of these benefits using statistics of installed capacity (MW), hectares of irrigated lands, and reservoir volume, respectively. We categorize magnitudes of these benefits by comparing benefits of Lancang and Nu River dams to those of other large dams in the country. In the case of China, we use the International Commission on Large Dams' (ICOLD) database of Chinese dams to extract hydropower, irrigation, and flood control data for each dam in question. We use percentiles to assign bins, calculating the percentile rank of all Chinese dams, and then defining threshold values for each subindicator based on values at the 33rd and 66th percentile. The largest subindicator value defines the overall bin, as follows:

> IF **DAM** provides no hydroelectricity OR flood control OR irrigation,
> THEN **NO IMPACT**
>
> IF **DAM** is 1st to 33rd percentile for hydroelectricity OR flood control OR irrigation, THEN **SMALL IMPACT**
>
> IF **DAM** is 34th to 66th percentile for hydroelectricity OR flood control OR irrigation, THEN **MODERATE IMPACT**
>
> IF **DAM** is over 66th percentile for hydroelectricity OR flood control OR irrigation,
> THEN **LARGE IMPACT**

For example, if a dam provides no irrigation or flood protection, but is in at the 40th percentile of installed hydroelectric capacity, the dam is categorized Moderate impact.

GP1 Subindicator 4: People resettled

Resettlement is a well-documented cost of large dams. People settle around rivers because they provide utility, and people who currently live near rivers depend—knowingly or not—on the ecosystem services the river provides. We assume that as the number of people forcibly resettled increases, shock to the domestic hydropolitical system also increases. Therefore, we evaluate the magnitude of domestic shock due to resettlement as the number of people resettled. We evaluated the number of people resettled by each project (Plinston and He 1999, Dore and Yu 2004) and calculated percentiles relative to the number of people displaced by other dams in China, as reported in the ICOLD database. For unbuilt dams without displacement numbers, we estimate displaced population based on the intersection of modeled reservoir polygons (See BP1) and a population grid.

Table 2.2: Hydropower potential, irrigated land, flood protection (reservoir volume), and resettlement costs of Lancang and Nu River dams.

Dam Name	Hydropower Potential (MW)	Irrigated Land (ha)	Flood Protection (reservoir volume) (m^3)	Resettlement (people)
Xiaowan	4200	unknown	unknown	26,880
Manwan	1500	unknown	unknown	3,513
Dachaoshan	1350	unknown	unknown	6,100
Nuozhadu	5850	unknown	unknown	23,826
Maji	4200	unknown	unknown	19,830
Lumadeng	2000	unknown	unknown	6,092
Yabiluo	1800	unknown	unknown	3,982
Lushui	2400	unknown	unknown	6,190

data sources: ICOLD World Register of Dams; Dore and Yu 2004; Plinston and He 1999

2.3.2 GP2: International Institutional Resilience

GP2 Subindicator 1: RBO/treaty score

New dam construction has the potential to strain international relations within a river basin. Treaties or river basin organizations (RBOs) that enable riparian nations to jointly manage international rivers have potential to attenuate stress and distribute costs and benefits resulting from dam construction—that is, robust transboundary institutions foster hydropolitical resilience. We follow De Stefano et al. [2010] in evaluating transboundary hydropolitical governance by measuring specific aspects of treaties or RBOs. For rivers that lie completely within one country, the benefit value is zero. De Stefano et al. [2010] code international basins on a scale of zero through four. Each country-basin unit within an international basin receives one point for each of the following attributes: 1) an international water treaty exists 2) a mechanism for allocating water among parties exists 3) a mechanism for managing flow variability exists, and 4) a mechanism for managing conflict exists. We then calculate the mean RBO/treaty score and percentile rank for each international basin and identify scores that correspond to the 33rd and 66th percentiles. If no treaty or RBO exists, the benefit value is zero.

GP2 Subindicator 2: River basin population

While the treaty/RBO score captures the ability of countries to cope with the shock of a dam on an international river, we define the number of people who live in the river basin as an indicator of those potentially exposed to negative effects of dam construction. We use the number of people in the basin, relative to all other international basins, as an indicator of transboundary hydropolitical vulnerability.

Table 2.3: RBO/treaty score and basin population for Lancang and Nu River dams.

Dam Name	River Basin	RBO/Treaty Score (number)	Basin Population (people)
Xiaowan Manwan Dachaoshan Nuozhadu	Mekong	1.27	59,000,000
Maji Lumadeng Yabiluo Lushui	Salween	no treaty	6,000,000

data source: De Stefano et al., 2010 (RBO/treaty scores).

2.3.3 GP3: Political Complexity

Basin-wide management may increase and induce dialogue that fosters improved inter-jurisdictional relations. Integrated Watershed Management (IWM) may lead to greater efficiencies in water allocation and use, as well as in other related areas such as forestry, irrigated agriculture, and transportation. We assume that the more boundaries a river crosses, the more complex the governance process must be to facilitate dialogue and decision making. We assume that decision makers view political complexity as a cost. We quantify both benefits and costs of political complexity based on the number and type of boundaries that the river crosses and define impact thresholds based on the following qualitative decision rules:

Benefit Scale

IF multiple national boundaries crossed, THEN **NO BENEFIT**

IF one national boundary crossed, THEN **SMALL BENEFIT**

IF boundaries of administrative unit below the nation-state crossed (e.g. states, provinces), THEN **MODERATE BENEFIT**

IF no administrative boundaries crossed, THEN **LARGE BENEFIT**

Cost Scale

IF no administrative boundaries crossed, THEN **NO COST**

IF boundaries of administrative unit below the nation-state crossed (e.g. states, provinces), THEN **SMALL COST**

IF one national boundary crossed, THEN **MODERATE COST**

IF multiple national boundaries crossed, THEN **LARGE COST**

Table 2.4: Political complexity of Mekong and Salween River Basins.

Dam Name	River Basin	Political Complexity
Xiaowan Manwan Dachaoshan Nuozhadu	Mekong	Multiple national boundaries crossed
Maji Lumadeng Yabiluo Lushui	Salween	Multiple national boundaries crossed

2.3.4 GP4: Legal Framework

Strong laws work to mitigate potential impacts of change while existing basin agreements and associated RBOs reduce vulnerability throughout the basin. Accordingly, if laws and other institutions are weak or nonexistent, they may have insufficient power to mitigate negative impacts or reduce vulnerability. We indicate robustness of the legal framework with respect to each dam by the highest administrative jurisdiction governing the dam. In China, the Lancang and Nu River dams are considered "national level" dams, and as a result are subject—in principle, at least—to national-level oversight based on laws and regulations governing Environmental Impact Assessment (EIA), resettlement compensation, and the like. We recognize that existence of laws and regulations does not necessarily ensure that laws are enforced, a phenomenon that should be at least partially captured by GP5, Transparency of Domestic Government. We define impact thresholds of benefits and costs of legal framework according to the following qualitative decision rules:

Benefit Scale

IF no relevant laws exist to govern the dam site, THEN **NO BENEFIT**

IF local-level (country, province, state) governance, THEN **SMALL BENEFIT**

IF national-level governance, THEN **MODERATE BENEFIT**

IF multi-national governance, THEN **LARGE BENEFIT**

Cost Scale

IF multi-national governance, THEN **NO COST**

IF national governance, THEN **SMALL COST**

IF local-level (county, province, state) governance, THEN **MODERATE COST**

IF no laws exist to govern the dam site, THEN **LARGE COST**

Table 2.5: Greatest administrative level of oversight for Lancang and Nu River dams.

Dam Name	Greatest Administrative Level
Xiaowan	National
Manwan	National
Dachaoshan	National
Nuozhadu	National
Maji	National
Lumadeng	National
Yabiluo	National
Lushui	National

2.3.5 GP5: Transparency of Domestic Government

A high level of democracy, as reflected by the Democracy Index, suggests that decision processes are open and transparent, governmental management capacity is robust, and civil dialogue is open and active. Conversely, when this is not the case, decision processes are often closed and obfuscated, governmental management capacity is often limited, and civil dialogue is limited or constrained. We use *The Economist*'s democracy index as an indicator of transparency, referencing the transparency of all nations and defining thresholds of impact at the 33rd and 66th percentiles. In this case, costs of low transparency are computed as the inverse of the benefit.

Table 2.6: Democracy index for Lancang and Nu River dams.

Dam Name	Democracy Index
Xiaowan	3.04
Manwan	3.04
Dachaoshan	3.04
Nuozhadu	3.04
Maji	3.04
Lumadeng	3.04
Yabiluo	3.04
Lushui	3.04

data source: Economist Intelligence Unit's Index of Democracy, *The Economist*, 2008.

2.3.6 GP6: Domestic Political Stability

Cooperation during planning, construction, operation, and management phases of dam development leads to the establishment or strengthening of institutional arrangements and promotes improved relations among domestic actors such as advocacy groups, administrative agencies, or individuals. On the other hand, lack of cooperation surrounding these processes or other conflicts related to the project increase tensions in relations among domestic groups. We assume that basins exhibiting more cooperation than the rest of the world are more likely to be stable after dam construction; conversely, basins that exhibit more conflict than the rest of the world are more vulnerable to conflict in the wake of dam construction.

To evaluate domestic political stability, we use an event chronology and domestic event intensity scale (Yoffe 2001, Yoffee et al. 2003) to identify instances of cooperation and conflict at the national level. We collected data on domestic events in China by searching Chinese newspapers, academic articles, and online sources. Using the Basins at Risk event intensity scale (Yoffe 2001, Yoffe et al. 2003), we code these events, associating benefits with cooperative events and costs with conflict. Specifically, we code cooperative events with intensities ranging from 0 to 6, and conflicts with event intensities in the range -6 to -1.

To properly categorize impacts related to event intensity, we refer to the average intensity of all domestic cooperative and conflicting events prior to dam construction. Because information regarding event intensity is available only at the scale of international river basins and not at the domestic scale, we use distributions of international event intensities (TFDD 2010) to categorize domestic political stability, defining impact thresholds at the 33rd and 66th percentiles of average international cooperative and conflictive event intensity.

In categorizing domestic events using distributions of international event intensity, we make the assumption that international and domestic events are qualitatively similar. This is likely untrue, as research by Aaron Wolf has shown that violence is more likely to occur at the local level than the international level. Because of this discrepancy, our evaluation of domestic political stability likely underestimates true potential for political instability. However, event intensity at the international level is the best available proxy for event intensity in China, thus we feel confident that data categorized using international distributions provides the best possible evaluation of potential for political stability in China.

Table 2.7: Domestic event intensity for Lancang and Nu Rivers.

Dam Name	River Basin	Domestic Event Intensity -Cooperation-	Domestic Event Intensity -Conflict-
Xiaowan Manwan Dachaoshan Nuozhadu	Mekong	1.33	-1.43
Maji Lumadeng Yabiluo Lushui	Salween	0.98	-1.55

2.3.7 GP7: International Political Stability

Instances of cooperation or conflict among riparian nations before dam construction reflect the potential for future cooperation or conflict. Lack of cooperation during planning, construction, and operation, and management phases, or other conflicts related to project, increases tensions in relations among actors at the international level. We assume that basins that exhibit more cooperation than the rest of the world are more likely to be stable after dam construction; conversely, basins that exhibit more conflict than the rest of the world are more vulnerable to conflict in the wake of dam construction.

To evaluate international political stability, we use an event chronology and the international event intensity scale to identify and code instances of cooperation and conflict. Using event data from the Transboundary Freshwater Dispute Database (TFDD, 2010), we compute the average intensity of cooperative and conflictive events in the international Mekong and Salween River basins. We associate benefits with cooperative events, which have event intensities in the range zero to 7, and associate costs with conflictive events, which have event intensities in the range -1 to -7. We use the global distribution of mean event intensities from all international river basins to categorize international political stability, defining impact thresholds at the 33rd and 66th percentiles of average international cooperative and conflictive event intensity.

Table 2.8: International event intensity for Mekong and Salween Rivers.

Dam Name	River Basin	International Event Intensity -Cooperation-	International Event Intensity -Conflict-
Xiaowan Manwan Dachaoshan Nuozhadu	Mekong	2.17	-1.07
Maji Lumadeng Yabiluo Lushui	Salween	2.60	-1.42

2.4 SOCIOECONOMIC DATA

The suite of socioeconomic (SE) indicators are informed by detailed data from household surveys implemented in the Nu River basin (July-October 2009) and Lancang River basin (July-October 2010).

Nu River sampling methods

To understand the perspective of local community members on hydropower development and conservation in the Nu River basin, a group of U.S. and Chinese researchers conducted household surveys within the Nujiang Lisu Autonomous Prefecture in 2009. Surveys took place in two counties (Fugong and Lushui) encompassing 13 townships and 20 villages. Our sampling frame was established to include both upstream and downstream communities related to four proposed dam sites: Maji, Lumadeng, Yabiluo and Lushui. The total sample size was 405 households. Households were asked to provide information on a range of issues related to income, livelihood activities, ethnic and cultural identity, community participation, and education. In addition, the research team conducted qualitative interviews with a random subsample of 48 households that participated in the surveys, asking questions about the perceived benefits and costs of dam construction, and the means available to villagers for coping with potential changes to their lives and livelihoods.

Lancang River sampling methods

We implemented household surveys in 2010 from the Lancang River valley in central and southern Yunnan, China. In total, 843 households were surveyed. Specific topics of inquiry ranged from age, gender, health, ethnicity, education level, many aspects of agricultural production, participation in village activities, and many other variables.

Sample sites were stratified by dam location and resettlement status (resettled, planned for resettlement, and no resettlement planned). We sampled households within four counties. In Yun County, households were surveyed under the resettlement implemented and resettlement planned categories at both the Manwan and Dachaoshan Dam sites. In Fengqing County, households in these same two categories were surveyed at the

Xiaowan Dam site, which was completed in 2010. In Lancang County, at the Nuozhadu Dam construction site, households under all three categories of resettlement were surveyed. Lastly, in Jingdong County, only households with resettlement planned and households with no planned resettlement were surveyed. In total, households were sampled from 42 natural villages across all four counties.

The IDAM model fundamentally assesses impacts of dams, which implies that our measurements convey potential for change. As SE indicators are evaluated by examination of cross-sectional (i.e., snapshot) data, we assume that socioeconomic characteristics are relatively similar across different sampling sites.

2.4.1 Categorizing impact magnitude using z-score

We process responses from surveys at the village level, and often compare each location to the empirical distribution of all villages in the sample, using statistics of z-score (Eq. 2.1) to standardize each measure. In Eq. 2.1, individual is the mean of the displaced or to be displaced population, the sample mean is the mean of the entire sample (all villages surveyed), and sample stdev is the standard deviation of the entire sample.

$$\mathrm{z-score} = \frac{(\mathrm{individual} - \mathrm{sample\ mean})}{\mathrm{sample\ stdev}} \qquad \text{Eq. 2.1}$$

Z-score conveys how a particular village compares to the entire sample. A negative z-score indicates that an attribute of an individual village is lower than the mean of all households or all villages while a positive z-score indicates that the village is greater than the mean. Negative and positive z-scores are interpreted as respective costs and benefits to the system. We categorize z-score according to the following decision rules, where thresholds in z-score correspond to 5th, 33rd and 66th percentiles of the empirical distribution of villages surveyed:

IF **Z-SCORE** < -0.06 OR **Z-SCORE** > 0.06, THEN **NO IMPACT**

IF **Z-SCORE** is -0.07 to -0.42 OR **Z-SCORE** is 0.07 to 0.42, THEN **SMALL IMPACT**

IF **Z-SCORE** is -0.43 to -0.96 OR **Z-SCORE** is 0.43 to 0.96, THEN **MODERATE IMPACT**

IF **Z-SCORE** < -0.97 OR **Z-SCORE** > 0.97, THEN **LARGE IMPACT**

Lower z-score values translate to lower benefits and greater costs, such that being poorer, less networked, less educated, etc. than the mean indicates greater potential for negative effects and less potential benefit. Often, more than one attribute or subindicator is examined to inform one indicator, for example, as in the case of SE1 Social Cohesion where networks of borrowing, lending, and labor, attitudes about the village, and participation in village activities are combined. We compute z-score at the level of each individual subindicator, and then average positive and negative z-scores to determine final benefit and cost magnitudes.

2.4.2 SE1: Social Cohesion

Social cohesion refers to the degree to which community members maintain interdependence with one another through relationships of trust and reciprocity. Such relationships reinforce a community's ability to adapt to changes or stresses. They enable people to cooperate for mutual advantage. Existing literature suggests that displacement and resettlement alter social cohesion. As a measurement of social cohesion, the socioeconomic survey queries villagers about agricultural labor-sharing activities with their neighbors, feelings about village life, and their level of participation in organizations such as village committees.

SE1 Subindicator 1: Borrowing, lending, and labor-sharing networks

Villagers are asked whether they have ever borrowed or lent money to fellow villagers and whether they have participated in labor sharing activities with members of their community. Both questions return binary responses, yes or no answers corresponding to 1 and 0, respectively, which we average. We compute mean response of the displaced or to-be-displaced villages and compare to the sample population by computing a z-score.

SE1 Subindicator 2: Attitudes about the village

Villagers are read a series of 17 statements describing attitudes towards the village, to which they may strongly disagree (0), feel neutrally (0.5), or strongly agree (1). We average responses to these 17 statements and then compute mean response of the displaced or to-be-displaced villages and compare to the sample population by computing a z-score.

SE1 Subindicator 3: Participation in village activities

Villagers are read a series of 5 statements describing participation in village activities, to which they may strongly disagree (0), feel neutrally (0.5), or strongly agree (1). We average responses to these 5 statements and then compute mean response of the displaced or to-be-displaced villages and compare to the sample population by computing a z-score.

Table 2.9: Social cohesion in villages near Lancang and Nu River dams.

Dam Name	Community Networks (z-score)	Community Attitudes (z-score)	Community Participation (z-score)
Xiaowan	0.366	-0.074	-0.147
Manwan	0.323	0.074	-0.027
Dachaoshan	0.294	0.684	0.067
Nuozhadu	-0.726	0.240	0.309
Maji	-0.368	0.356	-0.266
Lumadeng	0.386	-0.468	0.293
Yabiluo	-0.013	0.331	-0.297
Lushui	-0.287	-0.456	0.326

2.4.3 SE2: Cultural Knowledge and Behavior

Cultural knowledge and behavior refer to the things people know and do which allow them to function effectively in a given culture. We measure cultural knowledge and behavior as an index of ethnic diversity and middle school enrollment rates.

SE2 Subindicator 1: Ethnic diversity

We compute an index of ethnic diversity for each village using Eq. 2.2, where p is the proportion of individuals in a village who identify themselves as a particular ethnic group, and N is the number of total ethnicities in the village.

$$\text{diversity} = 1 - \sum_{i=1}^{N} p^2 \qquad \text{Eq. 2.2}$$

We then compute village diversity z-score, comparing diversity of the displaced or to-be-displaced villages to the diversity of the sampled population..

SE2 Subindicator 2: School enrollment

We calculate percentages of middle school-aged children who are enrolled in school and compute z-scores for school enrollment in each village.

Table 2.10: Cultural knowledge and behavior in villages near Lancang and Nu River dams.

Dam Name	Ethnic Diversity (z-score)	Middle School Enrollment (z-score)
Xiaowan	-1.589	0.439
Manwan	-0.165	0.084
Dachaoshan	-1.247	-2.480
Nuozhadu	0.157	0.439
Maji	0.320	0.554
Lumadeng	-0.858	0.554
Yabiluo	0.321	0.554
Lushui	0.059	-0.042

2.4.4 SE3: Loss of Material Culture

Material culture refers to the things people use as a part of their subsistence, ritual, or other cultural activities. Literature suggests that one of the most important social impacts of dams relates to loss of cultural resources by inundation. We measure loss of material culture by damage to village resources and family tombs.

Villagers are asked whether they have lost or will lose village resources, such as schools, clinics and religious sites, or family tombs as a direct result of dam construction. Both questions return binary responses, yes or no answers corresponding to 1 and 0, respectively, which we average. We then compute mean response of the displaced or to-be-displaced villages and categorize mean dam-level impact into three equal bins, using the following decision rules:

IF **IMPACT** ≅ zero, THEN **NO IMPACT**

IF 0 < **IMPACT** <= 0.33, THEN **SMALL IMPACT**

IF 0.33 < **IMPACT** <= 0.66, THEN **MODERATE IMPACT**

IF **IMPACT** > 0.66, THEN **LARGE IMPACT**

Table 2.11: Loss of material culture from villages near Lancang and Nu River dams.

Dam Name	Loss of Material Culture (mean)
Xiaowan	0.500
Manwan	0.869
Dachaoshan	0.500
Nuozhadu	0.500
Maji	0.000
Lumadeng	0.642
Yabiluo	0.167
Lushui	0.500

2.4.5 SE4: Infrastructure

Dams may alter access to supportive infrastructure, including water, electricity, and transportation, and may affect both availability and price. We evaluate potential effects to infrastructure by considering the Chinese "three connections" (santong): water, electricity, and roads.

SE4 Subindicator 1: Water quality

Villagers are asked how many days in the preceding month their water supply was contaminated (unsafe to drink). We compute mean response of the displaced or to-be-displaced villages and compare to the sample population by computing a z-score.

SE4 Subindicator 2: Access to electricity

Villagers are asked how many hours of electricity they are able to access in a given week. We compute mean response of the displaced or to-be-displaced villages and compare to the sample population by computing a z-score.

SE4 Subindicator 3: Road access

Villagers are asked to approximate their travel time (on foot) to the nearest road. We compute mean response of the displaced or to-be-displaced villages and compare to the sample population by computing a z-score.

Table 2.12: Infrastructure in villages near Lancang and Nu River dams.

Dam Name	Water (z-score)	Electricity (z-score)	Roads (z-score)
Xiaowan	0.000	0.041	1.040
Manwan	0.000	0.083	-0.772
Dachaoshan	0.000	-0.723	0.152
Nuozhadu	0.000	2.245	1.040
Maji	0.000	-1.274	-0.562
Lumadeng	0.000	0.222	-0.335
Yabiluo	0.000	0.222	-0.551
Lushui	0.000	0.222	0.680

2.4.6 SE5: Income

Income represents a basic measure of well-being for rural households. Dams may alter the incomes of a study population. For instance, incomes may rise as off-farm opportunities for labor on dam construction become available, or government subsidies take effect. However, incomes may decrease with inundation of agricultural land and decreased crop yields. We compute mean household income of the displaced or to-be-displaced villages and compare to the sample population by computing a z-score.

Table 2.13: Household income in villages near Lancang and Nu River dams.

Dam Name	Household Income (z-score)
Xiaowan	0.065
Manwan	-0.160
Dachaoshan	-0.043
Nuozhadu	0.542
Maji	-0.173
Lumadeng	0.430
Yabiluo	-0.292
Lushui	-0.145

2.4.7 SE6: Wealth

Wealth is the accumulated assets of a household that allow them to support themselves and plan for the future. In rural China, the most important asset is one's home. We measure housing values as a proxy for wealth. Housing values may increase with relocation as people move into more modern houses. Alternatively, housing values may decrease if compensation levels are not adequate. We ask villagers to approximate the size of their house, and compute living space per person in each household, which we use as a proxy of housing value. We compute mean housing value at displaced or to-be-displaced villages and compare to the sample population by computing a z-score.

Table 2.14: Housing value in villages near Lancang and Nu River dams.

Dam Name	Housing Value (z-score)
Xiaowan	-0.156
Manwan	-0.282
Dachaoshan	-0.233
Nuozhadu	1.133
Maji	-0.055
Lumadeng	0.007
Yabiluo	-0.289
Lushui	0.282

2.4.8 SE7: Macroeconomic Impact

The commercial value of hydropower is a major impetus for building dams and impacts to infrastructure, tourism, and related industries may also occur. However, economic costs of resettlement for displaced people may be considerable. This indicator is meant to measure the economic impact of a dam on a regional or national scale, including both economic benefits and losses. We measure macroeconomic impact by commercial value of hydropower and spending on related infrastructure; and resettlement costs.

We compute total positive macroeconomic impact as the sum of total project investment and a 100-year net present value of hydropower output. Projected annual electricity production statistics reported by are multiplied by grid price set by the Yunnan Province Development and Reform Commission (2006), and are discounted at a rate of 5% annually. We assume no depreciation in hydropower output and no change in real price of electricity. We categorize the magnitude of impact into three equal bins by comparing to the sample maximum and following these rules:

IF **IMPACT** = zero, THEN **NO IMPACT**

IF 0 < **IMPACT** <= (max impact/3), THEN **SMALL IMPACT**

IF (max impact/3) < **IMPACT** <= (2*(max impact/3)), THEN **MODERATE IMPACT**

IF **IMPACT** > (2*(max impact/3)), THEN **LARGE IMPACT**

SE7 Subindicator 2: Resettlement costs

Total resettlement costs are estimated by multiplying the number resettled by 60,000 RMB. We categorize the magnitude of impact into three equal bins with reference to the sample maximum according to the following rules:

IF **IMPACT** = zero, THEN **NO IMPACT**

IF 0 < **IMPACT** <= (max impact/3), THEN **SMALL IMPACT**

IF (max impact/3) < **IMPACT** <= (2*(max impact/3)), THEN **MODERATE IMPACT**

IF **IMPACT** > (2*(max impact/3)), THEN **LARGE IMPACT**

Table 2.15: Macroeconomic impacts of Lancang and Nu River dams.

Dam Name	Commercial Value (Billion RMB)	Resettlement Cost (Billion RMB)
Xiaowan	103.3	1.964
Manwan	38.02	0.211
Dachaoshan	38.83	0.366
Nuozhadu	141.4	1.429
Maji	97.13	1.190
Lumadeng	31.60	0.239
Yabiluo	48.14	0.366
Lushui	46.25	0.371

2.5 BIOPHYSICAL DATA

IDAM biophysical (BP) indicators assess potential for dams to change the physical landscape and affect ecological integrity. Evaluating BP impacts of Nu and Lancang River dams is challenging, primarily because access to robust and accurate information in these basins is extremely limited. Hydropower development in both basins is a sensitive topic, thus data necessary to evaluate biophysical effects with a high degree of confidence is severely restricted.

Both the Nu and Lancang Rivers are international rivers, originating in China and crossing international borders from Yunnan Province, China into Burma and Lao, respectively. The Chinese government has an official policy of secrecy regarding hydrologic information of international rivers, thus basic information such as river stage, discharge, and sediment transport parameters are classified under the Chinese State Secrets Act and therefore unavailable. Similarly, Environmental Impact Assessment (EIA) reports containing valuable information regarding each dam's location and planned operations schedules, among other pertinent information, are also classified and not available to inform this study. IDAM impacts and indicators are designed to utilize information readily available in EIAs, therefore, in this particularly data-poor situation where fundamental information is classified, we rely heavily on modeling to provide information used in evaluation of biophysical dam impacts.

Given access restrictions to hydrologic and dam operations information, much uncertainty is associated with modeling potential biophysical effects of hydropower stations on the Lancang and Nu Rivers. We characterize uncertainty in our estimates of impact magnitudes by modeling maximum and minimum possible effects, within which we are confident true values are contained. For example, uncertainty associated with an estimated reservoir surface area comes from ambiguity in true dam location, fluctuations between minimum and maximum operational pool elevations, and differences in projected and actual maximum pool elevations. We address this uncertainty by modeling and reporting a minimum reservoir size, modeled at the most upstream location, and minimum pool, and a maximum reservoir size, modeled at the most downstream location with a maximum pool. We are confident that this range of minimum and maximum values captures possible configurations, considering uncertainty in final dam placement and seasonal variability of pool elevation.

2.5.1 Use of official and published values

In our evaluation of BP indicators, we refer to a suite of published, publically available statistics about proposed and existing dams on the Lancang and Nu Rivers. Published metrics regarding Lancang dams source from one report, published in 1993 by the Yunnan Provincial Science and Technology Commission, Yunnan Institute of Geography, but are reprinted by many authors, including Plinston and He [1999], the Mekong River Commission [2008], and the Asian Development Bank [2003]. Almost all data regarding Nu dams originally source from a report by Dore and Yu [2004]. Dore and Yu issue the following caveats to using this data as the letter of the law:

> *Details of dams remain subject to negotiation, redesign and variation. Different figures are used by sources for many variables, especially total energy and displaced people; but also for dam height and area to be inundated etc… For example, the developer of Jinghong is seeking approval to increase the installed capacity from 1,500 MW to 2,000 MW. The information has been pieced together from multiple sources, including developer proposals, researchers documents and media reports. The foundations are: for Nu data, the Huadian proposal; for Lancang, the published work of Plinston and He Daming (1999) and McCormack (2001); for Jinsha, the Three Gorges and Huaneng development company documents.*

Where possible, we model or further investigate influential reservoir parameters that significantly affect IDAM impact magnitudes in order to provide more accurate estimates of total effect. For instance, we model reservoir surface areas and volumes of proposed reservoirs. In the case of reservoirs that have been completed or are well into the process of completion, we analyze aerial imagery in order to validate the accuracy of our reservoir modeling.

2.5.2 Categorizing impact magnitude using equal bins

Defining bins of equal measure is useful when populations are small, with low n such that cumulative distribution functions are not supported. In order to classify biophysical data into equal bins, we reference the maximum impact magnitude of each indicator within the population of the eight dams that comprise our study population and categorize impacts according to the following decision rules:

IF **IMPACT** = zero, THEN **NO IMPACT**

IF 0 < **IMPACT** <= (max impact/3), THEN **SMALL IMPACT**

IF (max impact/3) < **IMPACT** <= (2*(max impact/3)), THEN **MODERATE IMPACT**

IF **IMPACT** > (2*(max impact/3)), THEN **LARGE IMPACT**

2.5.3 Modeling

2.5.3.1 River basin modeling

Many IDAM biophysical indicators reference reservoir location and size parameters (surface area, volume), therefore we model the Nu and Lancang River basins and drainage networks, and then model reservoirs by integrating dams within modeled terrain and drainage networks. We model drainage networks within the Nu and Lancang River basins using the ArcHydro model in ArcGIS 9.3.1 (ESRI, Redlands, CA), using an Advanced Spaceborne Thermal Emission Radiometer (ASTER) 30-meter Digital Elevation Model (DEM) (ASTER, 2009) as topographic data input to the ArcHydro model. The ASTER 30-meter DEM is the most detailed terrain model available for research in the Nu and Lancang Basins, as higher-resolution terrain models are classified.

To ensure accuracy of modeled streams, we defined several possible drainage networks characterized by a range of minimum drainage areas. We then confirmed locations of modeled rivers in situ and found that drainage models defined by cells to which at least 2000 cells (0.06 km^2) drained created a satisfactory approximation of the true drainage network.

2.5.3.2 Dam locations

We abstracted proposed dam locations from two published maps; one, a 1:3,550,000-scale map entitled "Lancang-Mekong Sub-Region Map of Economy and Communication", published in 2003, the second, a 1:180,000-scale map entitled "Yunnan Province Transportation and Communications Map" published in 2004. The error associated with interpreting mapped dam locations was within 1000 m. As potential dam locations may vary in two dimensions (up and downstream), we were able to isolate proposed dam locations to a 2000 m stretch of river.

In addition to mapping uncertainty, actual built locations of dams may change slightly from proposed locations as designs evolve, introducing uncertainty that proposed dam locations are where the dams are actually built. We asses potential ambiguities between proposed and final dam locations by comparing proposed locations of dams in the Lancang River basin with actual built locations of four dams, Xiaowan, Manwan, Dachaoshan, and Jinghong derived from 2002, 2003, and 2010 Landsat satellite imagery. Comparison of mapped proposed and actual built dam sites indicated that final dam locations were within 5000 m of proposed locations. Therefore, we evaluate total uncertainty with regard to large dam locations to ±5000 m from proposed locations.

2.5.3.3 Reservoir modeling

We model characteristics of proposed reservoirs by integrating published information about dam design and operation with an ASTER 30 m DEM. Modeled large reservoir parameters of interest such as surface area and volume are subject to a number of sources of uncertainty, including uncertainty in dam location, variability in operational pool elevation, and differences between proposed (before constructed) maximum pool elevations and actual (after constructed) maximum pool elevations.

Minimum pool elevations are not reported for proposed large dams on the Nu River, therefore we assess potential variations in operational pool elevation by analyzing patterns of operational pool range from six dams operating or under construction in the neighboring Lancang basin. Plinston and He [1999] report both maximum and minimum operational pool elevations for dams proposed on the Lancang River, allowing for calculation of the possible operational range of these reservoirs (Table 2.16). However, as more recent data obtained after several of the Lancang River dams had been constructed is also available, although not published (He Daming, pers. comm., January 2010), we include this most recent information in our modeling.

Table 2.16: Operational range reported for six large dams on the Lancang River mainstem.

Station Name	MAX pool elevation[2] (m)	MIN pool elevation[1] (m)	operational range (m)
Gongguoqiao	1319	1311	8
Xiaowan	1240	1162	78
Manwan	994	982	12
Dachaoshan	899	860	39
Nuozhadu	812	756	56
Jinghong	602	595	7

1 Plinston and He [1999]
2 He Daming, pers. comm., January 2010

We use the relationship between operational range and dam height of six large dams on the Lancang River to estimate potential minimum pool elevations and operational ranges of reservoirs on the Nu River, implicitly assuming that the relationship between dam height and operational range is equivalent in both basins. Heights of the six dams selected in the Lancang River encompass the range of dam heights proposed in the Nu River. However, the morphology of the Lancang basin differs from that of the Nu basin and it is possible that the dam height-operational range relationship in the Nu River is different from the Lancang River. Nonetheless, the relationship between dam height and operational range of dams on the Lancang (Figure 2.2) are the best available proxy for this relationship in the Nu River.

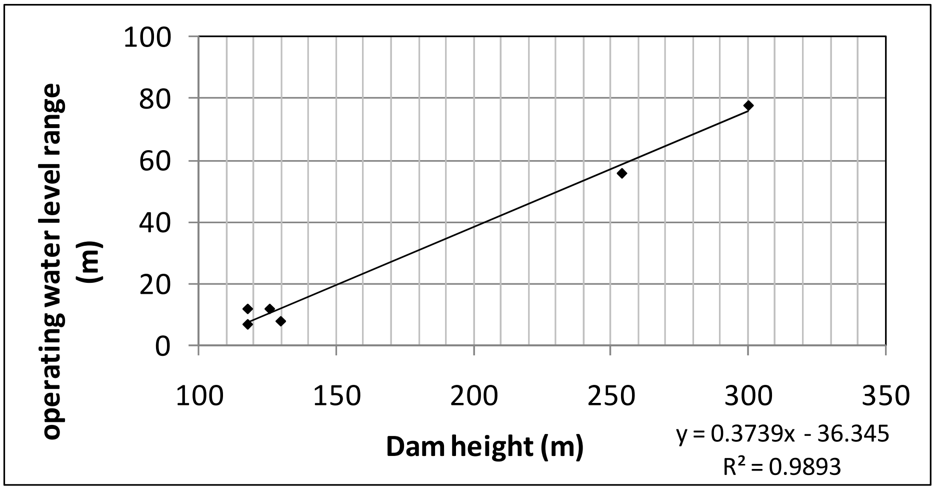


Figure 2.2: Relationship between operational range and dam height for dams on the Lancang River. We use this relationship to predict minimum pool elevations of dams on the Nu River (Table 2.17).

Table 2,17: Estimated operational range for dams on the Nu River.

Station Name	MAX pool elevation[2] (m)	MIN pool elevation[1] (m)	operational range[1] (m)
Maji	1570	1494	76
Lumadeng	1325	1300	25
Yabiluo	1060	1047	13
Lushui	955	926	29

1 Dore and Yu [2004]
2 estimated from relationship of operational range and dam height of six dams on the Lancang River (Figure 1).

Finally, there is some uncertainty in the projection of maximum operational elevation of the reservoirs. Data from dams that have already been built in the Lancang basin indicate that projected maximum pool elevation tended to vary ±4 m from the elevation reported after the reservoirs had been built. To account for this ambiguity, we incorporate an additional ±4 m to both the maximum and minimum pool elevations.

We model reservoirs using an ASTER 30 m DEM within ArcHydro tools for ArcGIS 9.3.1, evaluating uncertainty in reservoir size by modeling reservoirs at the most extreme possible conditions: at the most upstream and downstream possible dam locations and at the maximum and minimum possible pool elevations, resulting in a range of reservoir sizes within which the true size likely exists. We evaluate reservoir size parameters of area and volume using the maximum and minimum modeled reservoirs.

2.5.3.4 Landsat satellite imagery analysis

Because Manwan and Dachaoshan dams were built before the ASTER DEM data were collected, the reservoir surfaces interact with data sensors so as to obscure true ground elevations. As inland water masks are not applied to ASTER DEM data, we cannot accurately model Manwan and Dachaoshan reservoirs. We instead report reservoir areas for these two sites derived from analysis of satellite images (United States Geological Survey) of the Manwan and Dachaoshan reservoirs, taken on February 7, 2002 and October 5, 2002, when pools would have been at respective minimum and maximum elevations.

Xiaowan reservoir, was constructed after ASTER DEM data had been collected, allowing us to model the Xiaowan reservoir using the topography model. However, as the Xiaowan reservoir was filled in 2010-2011, we also analyze Landsat satellite imagery to determine the "true" reservoir size and serve as validation of the modeling. We find that the observed area of Xiaowan reservoir, determined by satellite image analysis, is within the bounds of modeled areas. Both observed and modeled areas of Xiaowan reservoir are many times the official estimates. This model validation indicates that our reservoir modeling may predict true reservoir area more accurately than government projections.

2.5.4 BP1: Impact area

As a reservoir is filled, terrestrial and riparian ecotones within the impoundment are transformed (Lewke and Buss, 1977; Oliver, 1974), and lotic aquatic habitats within the former channel become lentic environments (Petts, 1984), changing the habitat and resource base of local and regional ecosystems. To estimate the quantity of habitat disturbed by impoundments, we evaluate the area of land (km^2) and length of channel (km) inundated by the reservoir.

BP1 Subindicator 1: Area of terrestrial and riparian habitat inundated

We model reservoirs using an ASTER 30 m DEM within ArcHydro tools for ArcGIS 9.3.1, evaluating uncertainty in reservoir modeling by reporting results at the most extreme possible conditions: at the most upstream and downstream possible dam locations and at the maximum and minimum possible pool elevations. Our modeling results include a range of reservoir sizes which likely encompasses true reservoir area and seasonal variability.

Often our modeling indicates that reservoir size is substantially larger than that projected by official estimates (Table 2.18). In addition to modeling, we analyze Landsat satellite images (United States Geological Survey) to report reservoir areas for Manwan, Dachaoshan, and Xiaowan reservoirs. We analyze images of Manwan and Dachaoshan reservoirs taken on February 7, 2002 and October 5, 2002, times when the pools would have been at respective minimum and maximum elevations. Images taken on September 9, 2010 were digitized to assess the extent of Xiaowan reservoir, however as Xiaowan reservoir was still in the process of being filled at that time, this snapshot does not necessarily represent the maximum possible extent of the reservoir.

Because filling of Xiaowan reservoir commenced after data comprising the DEM were taken, we are able to model Xiaowan reservoir area and validate results by comparing to Landsat image analysis. We find that the observed area of Xiaowan reservoir, determined by aerial image analysis, is within the bounds of modeled areas. Both observed and modeled areas of Xiaowan reservoir are many times the official estimates. This model validation indicates that our reservoir modeling may predict true reservoir area more accurately than government projections.

Table 2.18: Area of terrestrial and riparian habitat inundated by maximum and minimum reservoirs on the Lancang and Nu Rivers.

Dam Name	MAX modeled reservoir area (km^2)	MIN modeled reservoir area (km^2)	reported reservoir area[1] (km^2)	Landsat MAX reservoir area (km^2)	Landsat MIN reservoir area (km^2)
Xiaowan	195	93	37.1	144	Na
Manwan	Na	Na	4.2	27	24
Dachaoshan	Na	Na	8.3	33	19
Nuozhadu	310	161	45.1	Na	Na
Maji	66	28	16.54	Na	Na
Lumadeng	11	3	4.41	Na	Na
Yabiluo	9	5	1.78	Na	Na
Lushui	18	7	3.95	Na	Na

1 data source: Lancang River dams: Plinston and He, 1999; Nu River dams: Dore and Yu, 2004;

BP1 Subindicator 2: Length of river channel inundated

We compare positions of minimum and maximum modeled reservoirs with modeled drainage networks, evaluating the lengths of tributaries and river mainstems inundated by the reservoirs.

Table 2.19: Lengths of river channel (aquatic habitat) inundated by maximum and minimum reservoirs on the Lancang and Nu Rivers.

Dam Name	MAX channel length (km)	MIN channel length (km)
Xiaowan	456	137
Manwan	108	99
Dachaoshan	168	112
Nuozhadu	688	360
Maji	156	65
Lumadeng	40	13
Yabiluo	34	19
Lushui	50	23

2.5.5 BP2: Habitat Diversity

Habitats transformed by inundation may vary in quality from the perspective of biodiversity conservation. To evaluated quality of disturbed habitats, we query the diversity of habitats inundated, as well as relationship of inundated areas to lands designated as priority areas for conservation.

BP2 Subindicator 1: Diversity of habitat types inundated

In order to determine the diversity of habitats inundated by reservoirs, we integrate modeled or observed maximum and minimum reservoir footprints (see BP1) with land cover data. We use 1-km^2 land cover data from the Global Land Cover Facility (Hansen et al., 2000) to characterize inundated habitat in the Nu and Lancang Basins. We calculate the number of habitats classified as one of fourteen potential land use classes[5] that may be lost as the reservoirs are filled. In our analysis, we include Cropland and Settlements as potentially disturbed habitat types, but do not include Water.

[5] Global Land Cover categories: Water, Conifer Forest, Evergreen Broadleaf Forest, Deciduous Needleleaf Forest, Deciduous Broadleaf Forest, Mixed Forest, Woodland, Wooded Grassland, Closed Shrubland, Open Shrubland, Grassland, Cropland, Bare Ground

Table 2.20: Number of habitats inundated by maximum and minimum reservoirs on the Lancang and Nu Rivers.

Dam Name	MAX habitats affected (number)	MIN habitats affected (number)
Xiaowan	8	7
Manwan	7	7
Dachaoshan	6	6
Nuozhadu	7	7
Maji	6	6
Lumadeng	4	4
Yabiluo	4	3
Lushui	4	3

BP2 Subindicator 2: Area priority conservation land inundated

Portions of the Nu and Lancang River basins are established priority areas for conservation of biodiversity and are protected or recognized at multiple institutional scales. To assess the potential for dams to affect lands designated as valuable for biodiversity, we look to designations of global, regional, and local conservation priorities that occur near or within the footprints of the reservoirs. At the global scale the United Nations Educational, Scientific, and Cultural Organization (UNESCO) has designated the Three Parallel Rivers of Yunnan as a World Heritage Site under the criteria of i) unique geological history, ii) dramatic expression of ecological processes, iii) superlative natural phenomena or natural beauty and aesthetic importance, and iv) biodiversity and threatened species (UNESCO, 2003). Additionally, The Nature Conservancy (TNC) and Conservation International (CI) have delineated areas of global importance for preserving biodiversity, Biodiversity Hotspots, within the Nu and Lancang basins. Portions of three CI Biodiversity Hotspots, the Himalaya, Mountains of Southwest China, and Indo-Burma Biodiversity Hotspots fall within the Nu and Lancang basins.

At the regional scale, comprehensive assessment and delineation of site-scale locations within our study area that possess global value as conservation priorities, termed Key Biodiversity Areas (KBAs) has been undertaken by a partnership consisting of Conservation International (CI), the International Conservation Union (IUCN), and the

Critical Ecosystems Partnerships Fund (CEPF) (Langhammer et al., 2007). KBAs are identified and delineated according to criteria of vulnerability and/or irreplaceability of species that are supported by the specific geographic location. Specifically, to be considered for KBA status, a site must contain or support globally significant numbers of at least one species listed as Critically Endangered, Endangered, or Vulnerable on the International Conservation Union (IUCN) Red List of Threatened and Endangered Species (IUCN, 2001), or support a globally significant percentage of any species' total population at any stage of life history (Langhammer et al., 2007). Globally significant numbers are defined based upon the IUNC Red List designation- a single individual of a Critically Endangered or Endangered species constitutes a globally significant number while 30 individuals or 10 breeding pairs of a Vulnerable species must be present to achieve globally significant numbers and thus qualify the site for KBA designation. Globally significant proportions of a species' total population vary according to the species' unique situation, but are generally defined as 1-5% of the global population.

To assess potential for dams to directly affect UNESCO World Heritage lands, TNC and CI Biodiversity Hotspots, KBAs and Nature Reserves, we calculate the area of designated land inundated by maximum and minimum reservoir footprints.

Table 2.21: Area of designated conservation land inundated by maximum and minimum reservoirs on the Lancang and Nu Rivers.

Dam Name	MAX conservation area inundated (km^2)	MIN conservation area inundated (km^2)
Xiaowan	94	24
Manwan	13	13
Dachaoshan	33	19
Nuozhadu	310	161
Maji	83	28
Lumadeng	11	3
Yabiluo	9	5
Lushui	19	7

BP2 Subindicator 3: Proximity to designated conservation lands

In addition to directly inundating designated conservation areas, dams may influence conservation lands indirectly by altering flows and habitat within the reservoir and downstream. To assess the potential for Lancang and Nu River dams to indirectly affect designated global or regional conservation priorities, we correlate proximity with intensity of effect, assuming that areas located closer to reservoirs are more likely to experience more severe effects. We therefore estimate the cumulative proximity of each project to designated conservation areas within the Mekong and Salween River Basins, creating an index of proximity computed by Equation 2.3 where P_{index} is the proximity index, d_i is the minimum distance between the footprint of the ith project and a conservation area (km), given a population of n conservation areas.

$$P_{index} = \sum_{i=1}^{n} \left(\frac{1}{d_i}\right) \qquad \text{Eq. 2.3}$$

Table 2.22: Proximity index, indicating cumulative proximity to designated conservation lands for maximum and minimum reservoirs on the Lancang and Nu Rivers.

Dam Name	MAX score (index)	MIN score (index)
Xiaowan	0.48	0.34
Manwan	0.30	0.30
Dachaoshan	0.29	0.27
Nuozhadu	0.27	0.26
Maji	1.04	0.36
Lumadeng	0.35	0.23
Yabiluo	0.50	0.45
Lushui	0.29	0.22

Limitations of conservation and biodiversity data in the Lancang and Nu River Basins

Among the many challenges presented by the harsh data environment of the Nu and Lancang basins, the paltry supply of data to determine potential effects of dams to biodiversity warrants particular mention. Global Biodiversity Hotspots, UNESCO boundaries, and KBA delineations are all subject to one common limitation which confines their utility in predicting conservation value of sites in the Mekong and Salween basins, which is that the priorities are delineated with minimal consideration of freshwater species (Langhammer et al., 2007; Long pers. comm., 2009). Although methods of site assessment and prioritization are established to incorporate considerations of the freshwater environment (Darwall and Vie, 2005), practitioners agree that the general lack of species data has hampered the extent to which these methods may be applied (Abell, 2002; Langhammer et al., 2007). To achieve transparency and justify conservation action based on Red List status, the IUCN mandates standards for adequacy of data used to designate a species as Threatened (Langhammer et al., 2007), which many freshwater species fail to meet. The lack of freshwater species data confounds the delineation of adequate priorities for conservation of freshwater life as species that lack comprehensive data are unlikely to be assessed for status as Threatened and thus sites that contain these species do not fit criteria for KBA designation.

Because little information is available regarding freshwater ecology in the Lancang, but especially in the Nu basin, freshwater conservation targets and corresponding protected areas do not exist, biasing analyses such as the one we have undertaken. For instance, in NW Yunnan, conservation areas (including the UNESCO Three Parallel River World Heritage Site) are delineated above 2000 m a.s.l. as a matter of practice (pers. comm. Long, 2009). It is unclear to what extent this practice is reactionary to plans for mainstem dams on the parallel rivers, but the effect is to undervalue aquatic habitats in favor of montane habitats favored by more charismatic terrestrial species for which data are in supply to justify protection, such as the Yunnan Golden Monkey.

2.5.6 BP3: Carbon Emission Reduction

The primary environmental benefit provided by hydropower projects is generation of renewable energy with few emissions of greenhouse gases. We used the United Nations Framework Convention on Climate Change (UNFCC) and Convention-Cadre des Nations Unies sur les Changements Climatiques (CCNUCC)'s "Consolidated Baseline Methodology for Grid-Connected Electricity Generation from Renewable Sources" (UNFCC and CCNUCC, 2010) to estimate potential emission reductions of large and small hydropower projects. Annual emission reductions are calculated according to Eq. 2.4 where ER is the total emission reduction of project, BE is the baseline emission, PE is the project emission, and L is the project leakage, all measured in metric tons of carbon.

$$\mathrm{ER} = \mathrm{BE} - \mathrm{PE} - \mathrm{L} \qquad \text{Eq. 2.4}$$

Hydropower projects requiring construction of a new reservoir determine their need to estimate project emissions of CO_2 and methane (CH_4) based upon an index of power density, determined by ratios of installed capacity and reservoir area.

Table 2.23: Thresholds of power density for calculating Certified Emissions Reductions (CERs) for hydropower projects including reservoir construction under UNFCCC's ACM0002.

Power density ≤ 4 Wm^{-2}	Power density 4.1-10 Wm^{-2}	Power density > 10 Wm^{-2}
project not eligible for emission reduction credits	project eligible with emission factor of 90g CO_2eq/kWh	project eligible and project emissions assumed negligible

Leakage from hydropower plants is assumed negligible under UNFCCC methodology, thus the total emission reduction of a new hydropower plant with a power density greater than 10 W/m^2 is equal to the baseline emissions, determined according to Equation 2.5, where ER is the total emission reduction of project and BE is the baseline emission, both measured in metric tons of carbon, EG is the annual electricity generated by project in MWh, and EF is the emission factor of baseline energy production in metric tons of CO2 per MWh.

$$\mathrm{ER} = \mathrm{BE} = \mathrm{EG} \times \mathrm{EF} \qquad \text{Eq. 2.5}$$

In calculating of the total emission reduction, we used emission factors of baseline energy production in Yunnan Province reported in a recent (September 2009) CDM PDD for the Labuluo small hydropower station (UNFCCC and CCNUCC, 2009), a hydropower project in the Nu River basin, and one of the projects analyzed in this investigation. Baseline emission factors are estimates of emissions generated by power production supplied by the local grid, in this case the China Southern Power Grid, which theoretically will be displaced by the proposed hydropower project. The emission factor of the China Southern Power Grid is 0.8712 tons CO_2/kWh (UNFCCC and CCNUCC, 2009).

Table 2.24: Certified emissions reductions from hydropower dams on the Lancang and Nu Rivers.

Dam Name	Annual CER (tons CO_2eq)
Xiaowan	16.5E+06
Manwan	6.8E+06
Dachaoshan	6.1E+06
Nuozhadu	20.7E+06
Maji	16.5E+06
Lumadeng	8.8E+06
Yabiluo	7.9E+06
Lushui	12.0E+06

2.5.7 BP4: Landscape Stability

Construction of hydropower facilities often entails expansion of power transmission routes and roads to the dam and power generation sites, increasing probabilities of land disturbance and landslides in the vicinity of the project. Additionally, filling of reservoirs is often associated with intensified seismicity near hydropower facilities (Gupta, 2002; Talwani, 1997). Empirical data suggests that parameters of reservoir depth, volume, and proximity to active faults are associated with increased probability of reservoir-triggered seismicity, with most documented cases occurring near reservoirs over 92 m in depth and 12E8 m^3 in volume (Baecher and Keeney, 1982). Zipingpu Reservoir, believed to have exacerbated seismic conditions leading to the 2008 Wenchuan earthquake in Western Sichuan Province, has a maximum depth and volume of 155 m, and $320x10^6$ m^3 and was located within a kilometer of the ruptured Beichuan fault (Klose, 2008; Moore, 2009). However, seismic events have also been triggered by much smaller reservoirs (Chen and Talwani, 1998).

BP4 Subindicator 1: Severe to high landslide risk lands inundated

In order to assess potential for exacerbation of local landslide hazards, we integrated project footprints with landslide risk information, derived from statistical analysis of landslide occurrence and slope, vegetation cover, precipitation, and proximity to roads (Li, 2010) and computed areas of high and severe landslide risk affected by each project.

Table 2.25: Area characterized as severe and high landslide risk inundated by maximum and minimum reservoirs on the Lancang and Nu Rivers.

Dam Name	MAX landslide risk (km^2)	MIN landslide risk (km^2)
Xiaowan	9.70	4.55
Manwan	0.02	<0.01
Dachaoshan	0.18	0.02
Nuozhadu	24.69	6.27
Maji	56.60	20.71
Lumadeng	11.36	2.82
Yabiluo	8.97	4.28
Lushui	16.49	6.49

BP4 Subindicator 2: Potential for reservoir-induced seismicity

To evaluate potential for reservoirs to induce seismic events, we create a seismic index for each project (Eq. 2.6) with respect to maximum reservoir depth ($h_{max\ res}$) and volume ($vol_{max\ res}$), and minimum distance (1/d) to active faults (He and Tsukuda, 2003).

$$S_{index} = h_{max\ res} \times vol_{max\ res} \times \frac{1}{d} \qquad \text{Eq. 2.6}$$

Table 2.26: Parameters of reservoir-induced seismicity and seismicity index for maximum and minimum reservoirs on the Lancang and Nu Rivers.

Dam Name	Reservoir depth (m)	Reservoir storage volume (mcm)		Distance to active faults (km)		Seismicity index	
		MAX	MIN	MAX	MIN	MAX	MIN
Xiaowan	300	16,400	5,000	1	1	12.29	3.77
Manwan	126	900	700	1	1	0.42	0.34
Dachaoshan	110	900	700	18	18	0.01	0.01
Nuozhadu	254	23,700	8,500	1	1	15.00	5.39
Maji	300	6,100	1,600	1	1	4.54	1.16
Lumadeng	165	400	20	3	1	0.16	0.00
Yabiluo	133	400	100	1	1	0.14	0.04
Lushui	175	1,100	200	1	1	0.50	0.07

2.5.8 BP5: Sediment Flux

Dams disrupt natural fluxes of water and sediments through river systems (Poff et al., 1997; Bunn and Arthington, 2002; Vorosmarty, 2003; Petts and Gurnell, 2005), altering first-order determinants of the physical riverine environment that cascade to affect river morphology and ecology (Schmidt and Wilcock, 2008; Poff et al., 2007; Lytle and Poff, 2004). Retention of sediments in reservoirs may affect geomorphic processes in the downstream channel and delta, as well as the life of the reservoir. Trap efficiency of the reservoir and percentage of basin contributing to the dam may indicate the degree to which sediment transport processes will be disrupted by the dam. We index these two subindicators (reservoir trap efficiency and percent of basin upstream of dam) to indicate the extent to which the dam potentially disrupts sediment transport processes.

BP5 Subindicator 1: Reservoir trap efficiency

We estimate sediment trap efficiency of proposed reservoirs using Eq. 2.7 after Brune's [1953] trapping efficiency curve:

$$\text{reservoir trap efficiency} = 1 - \left(\frac{0.05}{\sqrt{\Delta\tau_R}}\right) \qquad \text{Eq. 2.7}$$

where $\Delta\tau_R$ is change in residence time, as calculated for the reservoir and free-flowing reach, as in Eq 2.8.

$$\Delta\tau_R = \tau_R(\text{reservoir}) - \tau_R(\text{free flowing reach}) \qquad \text{Eq. 2.8}$$

We evaluate residence time change by comparing ratios of reservoir volume and volume of free-flowing reaches to mean daily discharge, calculating the residence time of water through the reach (τ_R, days) using Equation 2.9 where vol_{reach} is the volume of the reservoir or free flowing reach (mcm) and Q is mean flow in m^3day^{-1}.

$$\tau_R = \frac{\text{vol}_{\text{reach}}}{Q} \qquad \text{Eq. 2.9}$$

We compute reservoir volume (see table 1 and table x) using the 3D Analyst extension in ArcGIS 9.3.1 (ESRI, Redlands, CA), using an ASTER 30-meter DEM (ASTER, 2009) as topographic data input. To estimate volume of undisturbed reaches, we estimate maximum and minimum reservoir lengths by overlaying modeled maximum and minimum reservoir footprints and modeled hydrologic networks. We calculate average channel gradients between the most upstream and downstream points of the reservoirs and determine cross-sectional channel area at the reported average flow condition using channel cross-sections extracted from an ASTER 30-m DEM. We select a channel cross-sectional area corresponding to stage at the mean annual flow by optimizing hydraulic radius, cross-sectional area, and discharge within the reservoir reach using Manning's Equation (Eq. 2.10, Kondolf and Piégay, 2003), using a default value of 0.025 to represent Manning's roughness (Chow, 1959).

$$Q = \frac{1.00}{n} \cdot AR^{\frac{2}{3}}S^{\frac{1}{2}} \qquad \text{Eq. 2.10}$$

Where Q is flow (m^3s^{-1}), n is Manning's roughness (unitless), A is cross-sectional flow area (m^2), R is hydraulic radius (m), and S is channel gradient (mm^{-1}).

Plinston and He [1999] and Dore and Yu [2004] provide estimates of average flows entering Lancang and Nu River reservoirs, respectively. As large reservoirs have potential to store water, it is desirable to calculate residence times using data describing outflows from reservoirs rather than flows entering reservoirs. However, information about operations of large dams on transboundary waters, such as the Lancang and Nu Rivers, are classified under Chinese State Secret regulations. Therefore, we assume that the large dams are operated as run-of-river projects and that outflow from the reservoir may be approximated by inflows. This is likely an incorrect assumption, and may result in under-prediction of residence times through large reservoirs. Therefore, it is likely that the changes in residence times and reservoir trap efficiencies reported herein are conservative and that more extreme changes may be expected.

Additionally, flow out of reservoirs may vary considerably around the average numbers reported, again depending on flood patterns and dam operations. For instance, if a power station were run to produce greater amounts of power during times of peak demand relative to baseloads (hydro-peaking), the maximum outflow from the reservoir may be much higher than the average outflow.

The differential timing of peak and baseflow releases are necessary to compute residence times through the reservoirs that capture variability of flows.

Table 2.27: Reported inflows to reservoirs on the Lancang and Nu Rivers.

Dam Name	mean discharge[1] (m^3s^{-1})
Xiaowan	1220
Manwan	1230
Dachaoshan	1340
Nuozhadu	1750
Maji	1270
Lumadeng	1330
Yabiluo	1430
Lushui	1500

Table 2.28: Trap efficiency of maximum and minimum reservoirs on the Lancang and Nu Rivers.

Dam Name	MAX trap efficiency	MIN trap efficiency
Xiaowan	0.92	0.86
Manwan	0.67	0.63
Dachaoshan	0.66	0.62
Nuozhadu	0.92	0.87
Maji	0.87	0.75
Lumadeng	0.48	0.01
Yabiluo	0.48	0.05
Lushui	0.68	0.24

BP5 Subindicator 2: Percent of basin contributing to reservoir

We mapped dam locations (see BP 1) and used an ASTER 30-meter DEM (ASTER, 2009) to model contributing basin areas to each dam, using the ArcHydro model (ESRI) for ArcGIS 9.3.1.

Table 2.29: Percentage of basin contributing to maximum and minimum reservoirs on the Lancang and Nu Rivers.

Dam Name	MAX catchment above dam (%)	MIN catchment above dam (%)
Xiaowan	13	13
Manwan	14	14
Dachaoshan	14	14
Nuozhadu	17	17
Maji	34	34
Lumadeng	34	34
Yabiluo	35	35
Lushui	35	35

2.5.9 BP6: Hydrologic Modification

Dams disrupt natural fluxes of water and sediments through river systems (Poff et al., 1997; Bunn and Arthington, 2002; Vorosmarty, 2003; Petts and Gurnell, 2005), altering first-order determinants of the physical riverine environment that cascade to affect river morphology and ecology (Schmidt and Wilcock, 2008; Poff et al., 2007; Lytle and Poff, 2004). To evaluate the potential for Lancang and Nu River dams to modify river flows, we consider the fraction of annual runoff controlled by each project according to Eq 2.11.

$$\text{storage coeffiecient} = \frac{\text{vol}_{\text{res}}}{\text{annual runoff}} \qquad \text{Eq. 2.11}$$

Table 2.30: Fraction of annual runoff stored by maximum and minimum reservoirs on the Lancang and Nu Rivers.

Dam Name	MAX storage coefficient	MIN storage coefficient
Xiaowan	0.43	0.13
Manwan	0.02	0.02
Dachaoshan	0.02	0.02
Nuozhadu	0.43	0.15
Maji	0.15	0.04
Lumadeng	0.01	<0.01
Yabiluo	0.01	<0.01
Lushui	0.02	<0.01

2.5.10 BP7: Water Quality

Processes affecting water quality such as biogeochemical spiraling and energy fluxes can change as flows are stored in the reservoir (Stanley and Doyle, 2002). To estimate potential for Lancang and Nu River hydropower stations to influence water quality, we evaluate percent change in residence time of water through the reservoir reach (See BP5 for methods related to residence time calculation).

Table 2.31: Percent change in residence time through reaches inundated by maximum and minimum reservoirs on the Lancang and Nu Rivers.

Dam Name	MAX residence time change (%)	MIN residence time change (%)
Xiaowan	30,000	26,400
Manwan	10,000	10,000
Dachaoshan	9,500	9,500
Nuozhadu	41,700	18,700
Maji	24,400	13,400
Lumadeng	17,400	2,600
Yabiluo	13,300	7,700
Lushui	32,000	10,500

Figure 2.3: Impacts of Lancang River dams.

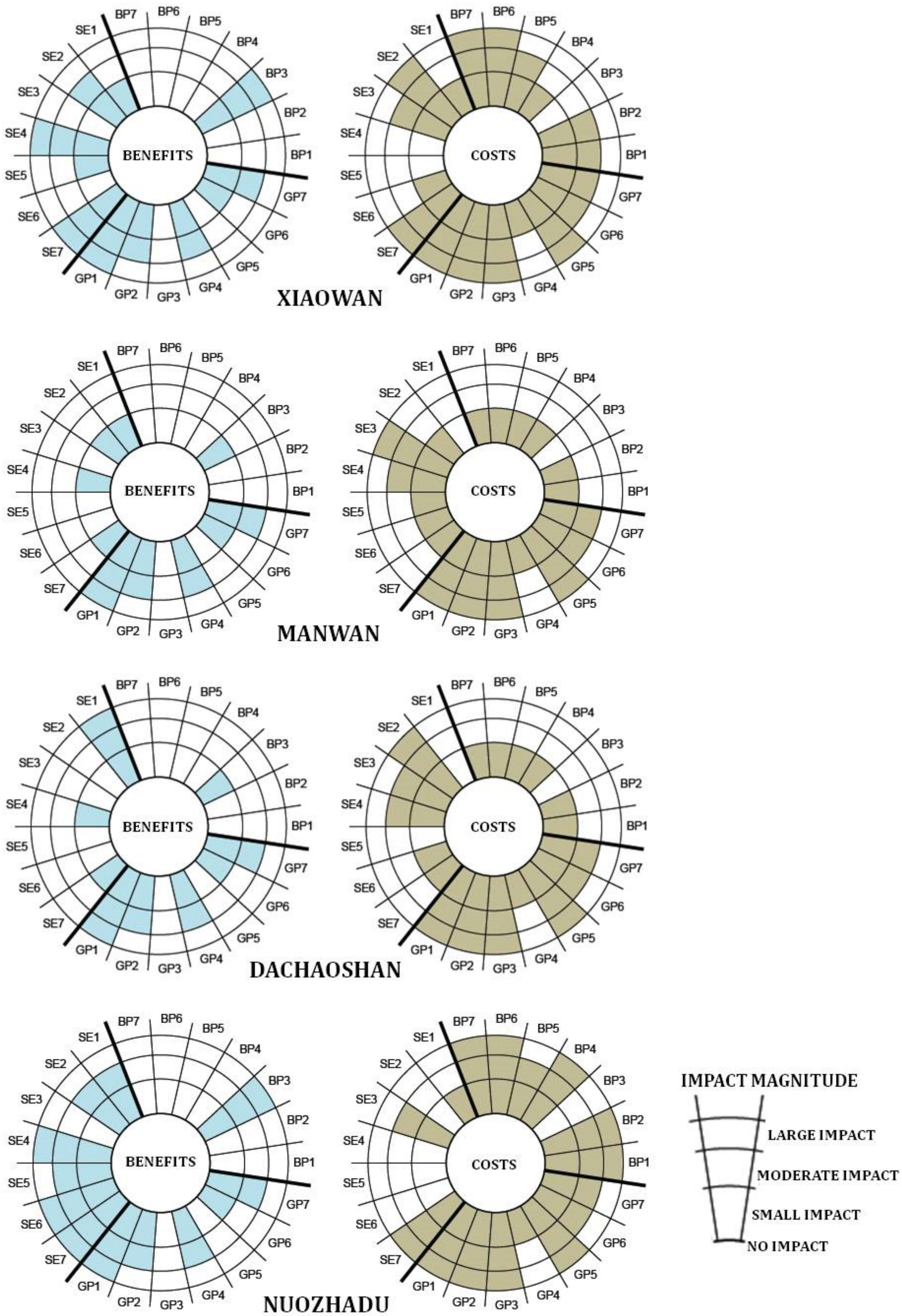
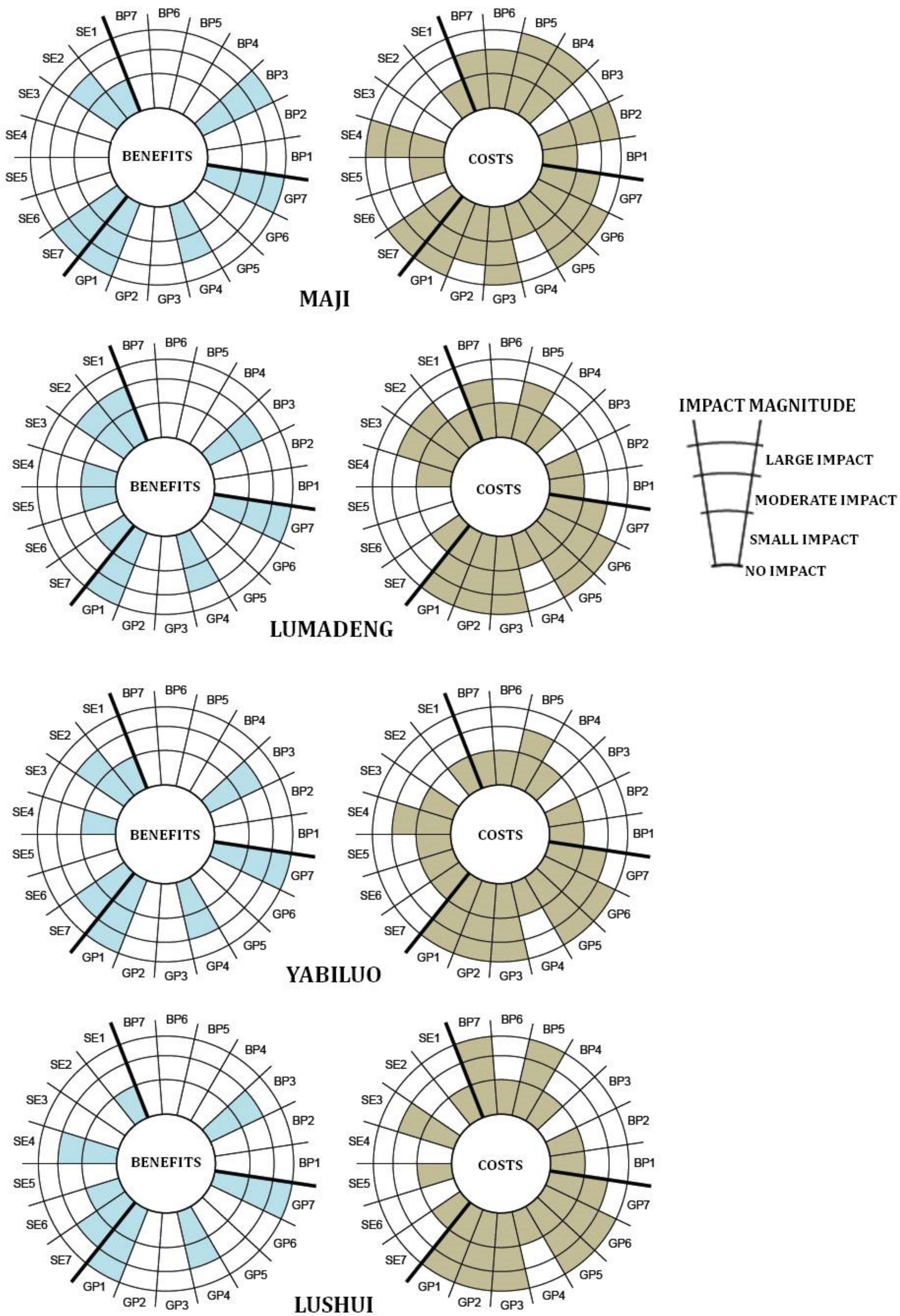


Figure 2.4: Impacts of Nu River dams.



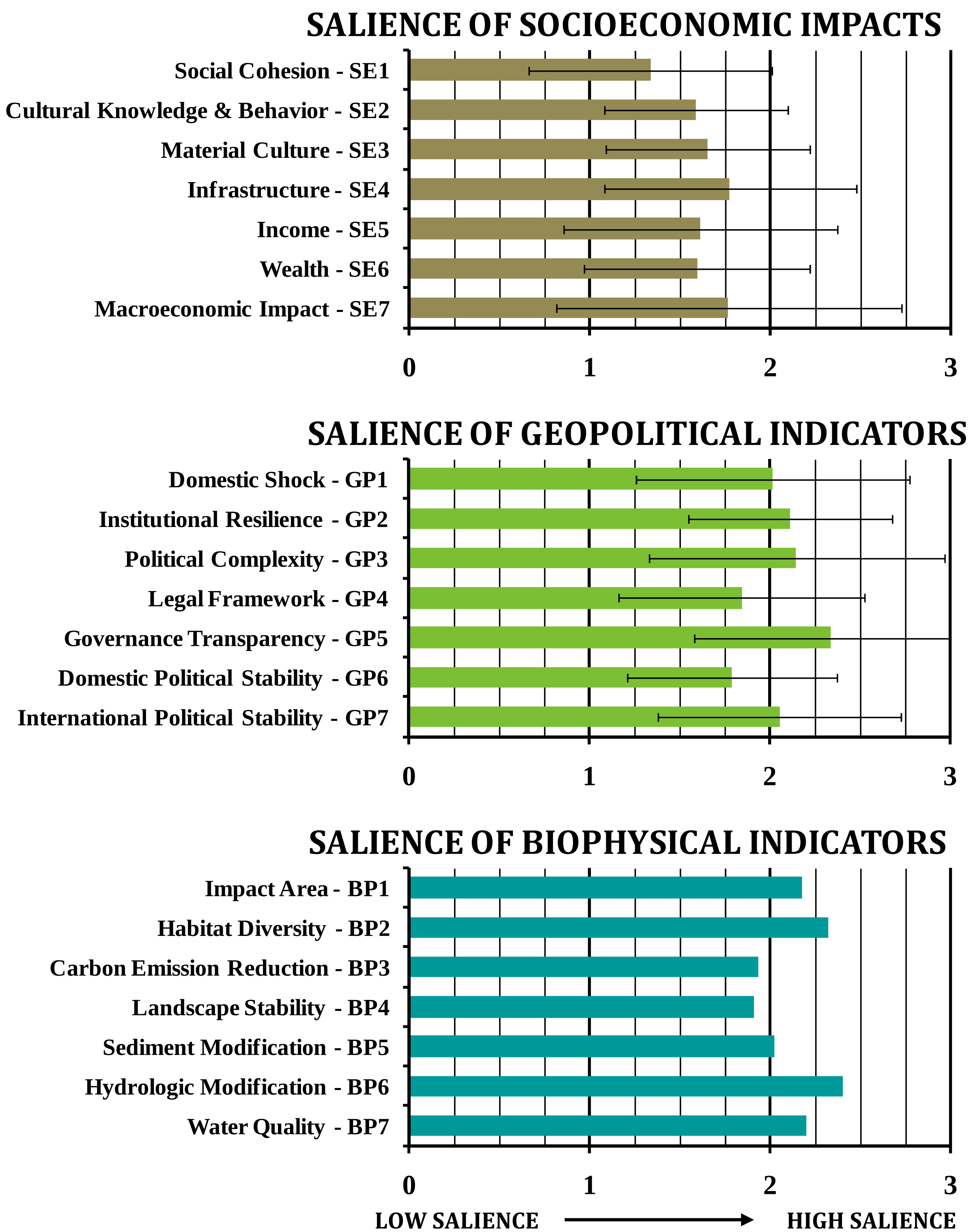
2.6 SALIENCE OF IMPACTS

On July 26 and 27, 2011, a group of dam and energy experts met at the Woodrow Wilson International Center for Scholars to participate in an event titled "Decision-making Around Dams: Data, Discussion, and Decision Theater". The objectives of this meeting were to:

- bring together dam and power sector experts and individuals engaged in hydro-development for a discussion around how decisions are made on the development of dams;
- present data on impacts of hydropower development in western China (Lancang and Nu River, Yunnan Province) and demonstrate IDAM tool to participating experts; and,
- explore participants' views on the salience of dam impacts and investigate decision rules influencing stakeholders' prioritization of hydro-development scenarios.

In a decision theater setting, participants were briefed on impacts of Lancang and Nu River dams and asked to contribute their opinions regarding importance of impacts. In the role of the stakeholder group, these expert "stakeholders" provide subjective valuation of impacts in the form of salience.

Figure 2.5: Mean salience of socioeconomic, geopolitical, and biophysical dam impacts. Error bars are one standard deviation.



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云南大学亚洲国际河流中心
Asian International Rivers Center

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