

**Review of Hydrology Component
Of
Environmental Assessment and Management Plan (EAMP)¹
For
Proposed Nam Theun 2 Hydropower Project
Lao People's Democratic Republic**

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January 20, 2005

Executive Summary

The hydrologic treatment of the Nam Theun 2 (NT2) Hydropower Project, contained in the Environmental Assessment and Management Plan, leads the independent reviewer to the conclusion that the project is high risk for meeting its power generation predictions and for estimating potential project impacts. Adequate hydrologic data and records are crucial to the viability of any hydropower project. This project plans to substantially dry up one river and divert the water into another. The consequences will be vast and difficult to predict: flooding, erosion, disruption of biological and human systems. Without reliable knowledge of the availability of water to turn the dam's turbines, project investors expose themselves to a high risk that electricity production will be less than expected. In addition, people living downstream of the project will be affected if river flows and their many physical consequences have been incorrectly estimated. Our analysis of project documents leads us to the following findings:

- The EAMP contains no hydrologic analysis, but contains references to unpublished supporting work. For much of the critical hydrologic analysis on which depends the entire assessment of the performance of the project and its environmental consequences, the Nam Theun 2 project sponsors have not provided the underlying data or explained the methodology used, thereby making robust independent analysis impossible.
- Project documents refer to many statistical correlations among real and synthesized data sets. The reviewer cannot discern whether any of these are adequate, and many appear questionable.
- Stream flow information is critical to this project, yet it is suspect; the deficiencies could compromise the project's stated ability to deliver sufficient flows for hydropower generation, as well as the assessment of project impacts.
- The project plans were initially drawn up on the basis of 9 years of extended rainfall records. The most recent EAMP relies upon additional data collected between 1994 and 2002, but even these numbers offer a maximum of an 18-year record, which is not a statistically valid basis for deriving 100-year and greater flood estimates.
- Significant changes in water elevation are predicted for the upper and middle reaches of the Xe Bang Fai River. Hydraulic modeling did not include these important reaches. Given the potential to affect not only the physical character of the Xe Bang Fai, but the

¹ November 2004 version

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social and ecological communities adjacent to the stream, it is essential that the best possible analytical methods be used to estimate the extent of these changes.

- 93% of the estimated reservoir inflow is planned for diversion to power generation. Any one of the many possible errors in the hydrologic analysis will result in various forms of degraded performance.
- Global climate change has been extensively documented, and promises to bring large changes worldwide to the hydrologic cycle and water supply. These changes have not been accounted for in the planning process for the Nam Theun 2 project, even though project feasibility and performance is highly vulnerable to perturbations related to climate change. Project planning has proceeded on the assumptions of traditional hydrologic analysis, that future hydrologic behavior will exhibit the same averages and range of variability as the past.

1. Adequacy of documentation of hydrologic analysis

The Nam Theun 2 Hydropower Project is a trans-basin diversion scheme proposed for central Laos. The project will drastically change the hydrologic regimes of two river basins because it will take water from the Nam Theun and divert it to the Xe Bang Fai. The most current authority on the hydrologic aspects of the project is Chapter 3 of the main Environmental Assessment and Management Plan, and Annex E to the plan. The main EAMP report describes a number of commonly used hydrologic analysis techniques, such as estimating missing streamflow data at a particular station by regression with other stations, or comparing catchment area ratios. The information in the report is entirely derivative however, and does not show any raw data, data quality, or specific methods. The reader turns to Annex E, entitled “Hydrological Data,” hoping to find this information. In fact Annex E contains no raw data whatsoever, nor does it contain any hydrologic analysis. Instead, it consists of a number of tables that have been calculated, estimated, or somehow derived for use in the analyses.

The EAMP contains no actual hydrologic analysis, but merely refers to unpublished supporting reports (SMEC 2003) that are not part of the EAMP and are not available to outside reviewers. Without access to these reports, the reviewer is constrained to base an evaluation on earlier work that was oriented to an outdated NT2 project design (SMEC 1996). The 1996 report contains summary information about basic hydrologic data, about which some judgments can be formed on the adequacy of the data that was available in 1996. While a few years of hydrographic data could be added to the latest part of the period of record, no additions could be made to the early part of the period.

Although it is typical and reasonable for an environmental impact document to include summary information taken from more detailed technical analysis reports, the summary information must be sufficiently detailed to include methods used, limitations of the methods, data used, and reliability of the results. Technical analyses reports are often appended to the main document, but at the least, must be made available to the public during the comment period. The U.S. Council on Environmental Quality (2004) says, on this issue,

. . . the appendix should contain information that reviewers will be likely to want to examine. Research papers directly relevant to the proposal, . . . discussion of the methodology of models used in the analysis of impacts, extremely detailed responses to comments, or other information, would be placed in the appendix . . . the appendix must

be complete and available at the time the EIS is filed.

A project of the scope and potential consequences of Nam Theun 2 should meet a similar standard. The hydrologic sections of the EAMP for this project lack sufficient detail. The reviewer needs a transparent view of what the project consultants did, and for the critical hydrologic analysis on which depends the entire assessment of the performance of the project and its environmental consequences, the Nam Theun 2 project sponsors have not provided the underlying data or explained the methodology used, thereby making robust independent analysis impossible.

2. Adequacy of hydrologic analysis

The design of a river basin project of the scope and consequences of the Nam Theun 2 Project raises three levels of issues: the adequacy of available data to support conventional hydrologic analysis techniques; the adequacy of those techniques to accurately represent known historical variability in hydrologic behavior; and the prospect of hydrologic behavior that is outside the bounds of historical observation. The following discussion will explore these three issues.

2.1 Statistical Methods

The primary approach to the Nam Theun - Xe Bang Fai hydrology is statistical analysis (SMEC 1996, p. 16). This was necessary because of a lack of long term stream flow monitoring, even at the all-important dam location on the Nam Theun, which has only been monitored since 1994. Gaps in the streamflow record have been filled by correlation with other river basins and areas in Laos and Thailand which have longer records (SMEC 1996, p. 19). In some cases, this correlation appears to be based simply upon catchment area ratios; in other cases (where Nam Ngum and Nakhon Phahnom data were used), a more sophisticated analysis using multiple variables may have been used, but there are no details in the EAMP which specifically state this or provide an indication of what variables were used or how they were used. Therefore the reviewer cannot determine whether any of these correlations are adequate, however many appear questionable. The site at Bridge 13 is backwatered from the Mekong River, yet data from that site was used to generate a correlation with Mukdahan. There are large disparities in catchment area - runoff ratios of stations used for correlation, which introduces unknown errors. Bridge 13 on the Xe Bang Fai, with a catchment of 8,560 km² is correlated with Mukdahan on the Mekong River, with a catchment of 391,000 km². The flow series at Mahaxai is based on a correlation with Ban Signo (SMEC 1996, p.23), which had a 9-year record with 24% of the data missing (Lahmeyer, 1997; p. 2). The unit runoff for the upper Nam Theun catchment is not comparable to that for the upper Xe Bang Fai (EAMP, p. 48), yet correlations of the two are still used to generate the flow series. The Ban Thalang site is similarly used (EAMP, p. 51, 60) in an inappropriate reliance on catchment ratios to estimate flows in a setting strongly influenced by monsoon storms and orographic⁴ precipitation patterns.

Further, there are numerous shortcomings in the parent data and the procedures that compromise the reliability of the result. The flow series are so heavily aggregated as to hide the original data. Synthetic flow series of monthly mean discharges are the sole basis for the conclusions.

⁴ Orographic means that, as a moisture-laden air mass lifts up a mountain front, it cools and its pressure decreases and its water vapor condenses into precipitation. Drier conditions occur on the leeward side.

Measures of the adequacy of the correlation method are completely missing. For example, it is not clear why, if daily flow measurements are available, the correlations and regressions were carried out on monthly averages. Statistical procedures are customarily accompanied by consistency checks, standard errors, correlation coefficients, evaluation of residuals, etc. These measures are the only way to distinguish whether the statistical exercise has resulted in spurious relationships. The raw derivative numbers are nearly meaningless by themselves.

2.2 Rating Curves and Estimation of Stream Discharge

Our knowledge of the river systems is entirely dependent on accurate water level measurements, and their accurate translation into instantaneous discharge either by means of a current meter measurement or a rating curve.⁵ There appear to be grounds for doubting both the water levels and the discharges, which are derived from a rating curve. It is not possible to tell from project documents how the rating curve was developed: what range of flows were used, how many of them were measured, how often the curve is checked with a current meter. The stability of the channel is most important. Fill or scour at a gauge site can introduce substantial error into the stage-discharge relationship, and render a rating curve inapplicable. The reviewer needs a transparent view of what the project consultants did, and the Nam Theun 2 project sponsors have made it impossible to reconstruct or understand their work.

While the methods are obscure, the results have known difficulties. There is no stable rating curve for the Xe Bang Fai River (EAMP, p. 48). The various rating curves have “problems,” and are “slightly inaccurate” (EAMP, p.49), yet there is no indication of what that means nor acknowledgement of how “slight inaccuracies” in the rating curve would propagate errors through an analysis of flood magnitudes. Flood flows could be more severe than predicted. Stream flow information is critical to this project, and unsound predictions could compromise both the project’s stated ability to deliver sufficient flows for hydropower generation and the assessment of consequent impacts.

Annex E contains synthesized flow series for five river stations of interest. The apparent procedure for generating these synthetic flows was to take the means of twice- or thrice-daily gauge height observations, and aggregate them into monthly mean discharges. Annex E expresses limited confidence in the underlying data:

. . . there is some degree of uncertainty in the measured water levels *and particularly the measured discharges* (emphasis added). When using standard field measurement

⁵ Current meter measurements are a direct way to measure stream flow: velocities are measured with an electromagnetic or impeller instrument designed for this purpose and along with velocity measurements, stream width and depth measurements are made and the whole represents a measurement of the instantaneous flow rate in the stream at the time the measurements were made. A rating curve is a relationship between a given stage (or water level) at a specific location in a stream and the discharge at that stage. The curve is usually defined through a series of simultaneous direct measurements using a current meter and stage readings.

procedures, the accuracy of field measurements of discharge is rarely greater than 10%.

2.3 Rainfall - Runoff Modeling

SMEC apparently relied in part on precipitation records to estimate flood hydrographs through rainfall-runoff modeling. While this is in general an acceptable means to make up for a lack of actual stream flow data if the rainfall record is robust and complete, it becomes more dubious when the precipitation record itself is short or incomplete. Several stations, including most of those within the project basins, began collecting data only in 1994 (SMEC 1996 Table 3.1). This means that only two years, at best, of data were obtained at those stations prior to their 1996 report. To ameliorate that obvious weakness, regression analyses were used to estimate missing data and extend periods of record based upon nearby stations with longer-term records. This too is generally acceptable. However, the resultant extended data sets were still only 9 years long (SMEC Table 3.3), and therefore of questionable use in estimating 100 year floods. The more recent EAMP apparently relies upon a newer SMEC report, which presumably used data collected between 1994 and 2002; however, those resultant data sets could still be no longer than 18 years, which is also questionable when deriving 100-year floods (Interagency Advisory Committee on Water Data, 1982). For thoughts on what is an adequate length of record, see discussion of Jain and Lall (2001), below.

In addition to the questionable assessment of temporal precipitation variability, the assessment of its spatial variability may also be inadequate. There is some discussion about this subject in SMEC's Section 3.3.3, including mention of the orographic influences on area precipitation, but it is not clear how this issue was eventually addressed in the flow modeling. It appears likely that the same stations used to extend the records at short-term stations may have also been used to then describe the spatial correlation between those same stations. This would essentially be using a set of numbers to estimate another set, and then using the first set to "prove" that the outcome is acceptable. If so, this raises statistical concerns because the data are not independent, thus violating the statistical premise of the analysis (USGS 2002). Again, inaccuracies, either due to a singular inappropriate method or an accumulation of unsound assumptions and foundation data, could compromise project premises and environmental impact assessment.

2.4 Estimation of Augmented Flows in the Xe Bang Fai River and their Effects on Water Levels

The EAMP (page 51) briefly describes predicted changes in flooded area and flood depth in the lower Xe Bang Fai (downstream of Bridge 13 to the confluence with the Mekong River) as a result of diverting flow to it from the Nam Theun. The discussion of the derivation of these numbers simply indicates that hydrologic and hydraulic models were used to predict these changes. Other than a mention of survey data and a statement that the models were calibrated and verified, information on the types of models, their limitations and assumptions, and the extent of the data inputs, is lacking. Regarding the hydraulic model, it is not clear whether a step-backwater model was used, or whether a less sophisticated method was applied. Given the fact that there is no water surface profile presented, one may assume that one was not generated. Additionally, one could ask whether a moveable bed function was used to account for the fact that the Xe Bang Fai's channel is - and will continue to be - quite active (EAMP page 36), and thus will also affect flood elevations and inundation area.

Furthermore, the above-mentioned hydraulic modeling was apparently only done for the

lowermost reach of the Xe Bang Fai. Although significant changes in water elevation are predicted for the upper and middle reaches (apparently based upon the stage-discharge curves), it is not clear why hydraulic modeling did not include these important reaches. The upper reach includes 12 villages with 852 households and the middle reach includes 12 villages with 668 households according to the EAMP (page 143), which is surely more than adequate justification for a complete hydraulic analysis. It is known that the backwater effect from the Mekong River extends upstream through the entire reach of the lower Xe Bang Fai and into its middle reach at least some distance upstream of Bridge 13, but this is simply used in the EAMP (page 51) to justify that “any prediction in terms of water level increase can only be approximate.” Given the potential to affect not only the physical aspects of the stream system of the Xe Bang Fai, but the social and ecological values adjacent to the stream, it is essential that the best possible analytical methods be used to estimate the extent of these changes. This should be done both for the typical increase in flows due to the daily plant operations and for the more extreme flooding events.

2.5 Reservoir operations and yield

The proposed operation of the NT2 project is predicated on the most optimistic assumptions, which means there is a risk of both economic underperformance and underestimated environmental consequences. The EAMP (Annex F) states the following:

. . . accuracy of the hydrological data could vary by as much as $\pm 10\%$ and with 93% of the estimated reservoir inflow being diverted for power generation in this simulation, the operation of the power station is likely to be sensitive to any error of the estimate of reservoir inflows. If the reservoir inflow was overestimated by 10% there would be less water for power generation.

Annex F continues by estimating the energy production shortfall associated with various levels of water shortage. The present analysis identifies many sources of uncertainty in the data supporting the NT2 proposal. Any one of these could account for an error as great as 10%, and they are likely to be additive rather than overlapping or canceling errors, thus the total error could be considerably larger. The EAMP does not describe possible total error bounds so the reader could see potentially how far off the analysis could be, nor has it described the consequences of various magnitudes of shortfall.

Annex F states that the 47-year simulation, which has all the weaknesses of a synthetic data series described elsewhere herein, shows a minimum reservoir level for the period. “However, this is not a trace of the reservoir level in the driest year, as not all the weekly minima occurred in the same year.” This characterization of minimum reservoir level does not define a conventional reservoir mass curve or storage-yield relationship, nor identify the critical low flow period, which is essential to determining whether the project will meet its objectives. Further, it apparently assumes no serial correlation among low flow weeks in the same year, i.e. that dry weeks don’t follow each other – obviously an unlikely scenario. The result is an unrealistic picture of regional hydrologic behavior.

Annex F reports that out of 47 years in the simulation, 18 years have some spill. This could, and probably will, be interpreted to mean that 38% of the years have spill. However the Table F.4 simulation shows that 85 weeks out of 1,924 weeks, or 4%, have spill – a rather different picture. The EAMP analysis is all reported in terms of average flows, which make it impossible to make

out any flow-duration or stage-duration picture. It is impossible to know how many weeks in the simulation period the project is able to produce its target generation.

3. Project Analysis in the context of Global Climate Change

The hydrologic investigations in support of the Nam Theun 2 project have spanned a decade. During that decade, a vast amount of insight and awareness about global climate change and its effect on water resources systems has accumulated. While there are those who choose not to believe the body of evidence that global warming has and will continue to operate, the present review finds persuasive the position taken on the matter by the American Geophysical Union (2003):

- Scientific evidence strongly indicates that natural influences cannot explain the rapid increase in global near-surface temperatures observed during the second half of the 20th century.
- Increasing atmospheric concentrations of carbon dioxide and other greenhouse gases will cause global surface climate to be warmer.
- The hydrologic cycle will change and intensify, leading to changes in water supply as well as flood and drought patterns.
- The global climate is changing and human activities are contributing to that change.

These insights have apparently not been incorporated into the planning for the Nam Theun 2 project, even though project feasibility and performance is highly vulnerable to perturbations related to large-scale climate change.

The heart of a dam design analysis is an interpretation of flow frequency and magnitude. Traditional flood frequency analysis makes assumptions that annual maximum flood peaks are independently and identically distributed, and that there is stochastic stationarity⁶ of climate phenomena, including extreme events. However, there is reason to doubt that this has always held true in the past, and even more reason to doubt that, with ongoing climate change, the assumption of stationarity will hold true in the near future. A summary of recent research findings will provide a useful perspective on the project's vulnerabilities.

Franks and Kuczera (2002) studied a 53-year record of flood flows in New South Wales, in which they observed two distinctly different climate states. These observations led them to the conclusion that reliance on the conventional assumptions is not warranted, and that an appreciation of flood risk requires an understanding of the different climate states. This cannot be done unless the different climate states in the flood record can be identified – which cannot be done without a statistically adequate hydrologic record.

Jain and Lall (2001) looked at the flood history in the 88-year record of the Similkameen River on the Canada - U.S. border in Washington State, and found that interannual, interdecadal, and longer time variations in planetary climate govern flood frequencies at timescales of importance to flood control system design and operation. A 30-year period is often considered to represent the climate of a region. When we know that a record contains interannual to interdecadal

⁶ Stationarity is the quality of a hydrologic record that assumes past statistical variability is the same as present and future variability, with the result that the past can be assumed to be a reliable guide to the future. In other words, future hydrologic behavior can be expected to be consistent with past behavior.

oscillatory variations, it is a bare minimum: Jain and Lall consider it to be the shortest window over which one may assess the stationarity or variability of the flood and climate records. They conclude that the last 30 years are not representative of the next 30 on the Similkameen.

In the face of these well recognized global weather phenomena, the Nam Theun 2 project analysis of 1996 depended on a hydrographic record consisting of 13 rainfall gauges, most of which had a record of one year of data or less. There are 19 stream gauges, of which (other than the mainstem Mekong River gauges), 13 had a record of ten years or less, and 8 were one year or less (SMEC 1996, p 17). The quality of this thin record is also subject to question. While additional data for some stations has accumulated since this report was done, some of the gauges were discontinued; and the maximum of eight additional years would still not provide a robust statistical sample.

Some investigators have found that the likely course of climate-change impacts on hydrologic systems may have the worst of both worlds. Tung (2001) applied three different global climate models to the Tseng Wen watershed in Taiwan, and found that all three predicted more serious flooding, at the same time increasing average temperatures and resulting evapotranspiration rates and irrigation water demand -- thus increasing water deficits by as much as 13%. Perturbations of this magnitude do not appear to have been incorporated into the design of the Nam Theun 2 project, with obvious consequences for a seasonal storage hydroelectric installation.

Nonstationarities in statistics of El Niño occurrences have become widely recognized (Dettinger, 1998). The 1997-8 El Niño resulted in warmer temperatures and more precipitation in the southwestern United States, and increasing probability of floods yet to come. There has also been a wide recognition of the need to integrate understanding of ENSO (El Niño-Southern Oscillation) dynamics in water resources decision-making. As far as the reader of the EAMP and its appendices can discern, this has not been done for the Nam Theun 2 project. If any of this thinking was done in the unpublished ancillary reports, it did not find its way into the EAMP.

Gershunov et al. (1999) find that long period oscillations in large-scale weather events are a global phenomenon. There are fundamentally different climate states associated with the different phases of these events. It is important to know what phase we are in because some prediction schemes work better for some phases than others. In planning huge irreversible commitments of water, money, and land that will affect whole populations of the target countries, it is most important to recognize these variations. More specifically, one effect of the El Niño - Southern Oscillation and the North Pacific Oscillation is to bias the likelihood of extreme events above or below the climatological norm over broad regions. Changes in frequency of extreme streamflows are even more severe than those for precipitation because of the nonlinear nature of the soil system in generating runoff from precipitation.

The literature of global climate change and low frequency periodicity of hydrologic phenomena is better developed for North America and Europe than for tropical and subtropical Asia. That does not mean these phenomena can be ignored. It is arguably the preeminent responsibility of the planners and financiers of large dams in developing countries, such as Nam Theun 2, to undertake this kind of analysis and relate it to their projects and target countries. Instead, planning for large dams such as the Nam Theun 2 project appear to be proceeding in the absence of planned adaptation to climate change. While the EAMP (Chapter 3, p. 29) has a section entitled "Global and Regional Issues," the section contains no reference whatsoever to shifting

global or regional climate patterns. The UN-sponsored Intergovernmental Panel on Climate Change (IPCC 2001) argues strenuously that adaptation to climate change is a necessary strategy at all scales, particularly in areas of high vulnerability such as developing countries.

Lest one think that subtropical Asia is exempt from climate phenomena observed elsewhere, several countries in this region have reported increasing surface temperature trends in recent decades. IPCC reports the following: In Vietnam, annual mean surface temperature has increased over the period 1895-1996, with mean warming estimated at 0.32° C over the past 3 decades. In India, Laos, the Philippines, and Vietnam, drought disasters are more frequent during years following ENSO events. At least half of the severe failures of the Indian summer monsoon since 1871 have occurred during El Niño years. In the event of enhanced anomalous warming of the eastern equatorial Pacific Ocean, such as that observed during the 1998 El Niño, a higher frequency of intense extreme events all across Asia is possible. Recent increasing frequency of floods and droughts in some areas of the world has affected social and economic systems. Large water resources systems in particular are vulnerable to climate change. In fact, the EAMP (page 47) itself notes that measurable changes in the Mekong over the past 75 years may be due to climate change.

Because much of tropical Asia is intrinsically linked with the annual monsoon cycle, a better understanding of the future behavior of the monsoon and its variability is warranted for economic planning, disaster mitigation, and development of adaptation strategies to cope with climate variability and climate change. Agriculture is one of the sectors that is most susceptible to climate change, so countries with a large portion of the economy in agriculture – such as Laos -- face a larger exposure to climate change than countries with a less significant agriculture sector.

A danger with hydroelectric projects that are over-optimistically designed to provide minimum bypass flows is that those flows will be readily sacrificed when drought conditions set in. This is now happening in Thailand, which is experiencing its worst drought for two decades. EGAT, the Thai national energy utility, has said that it may forego its commitments to fully open the Pak Mun Dam's gates to allow fish migrations for four months per year.

4. Summary

The planners of the Nam Theun - Xe Bang Fai trans-basin diversion propose to make irreversible commitments of the hydrologic integrity of two river basins in central Laos, the livelihoods of the current residents of these basins, and a large capital investment on the part of multilateral funding agencies. The underlying data is inadequate to sustain a conventional hydrologic analysis, and no analysis recognizing global climate change has been undertaken. The information in the EAMP is entirely derivative, and shows no raw data, data quality, or specific methods. Publicly available supporting documents also fail to provide this information. As a result of the deficiencies in raw data and in analysis, the reviewers must conclude that the project is high risk for meeting its power generation predictions and for estimating potential project impacts.

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