# Review of the Water Quality Assessment (EAMP) Proposed Nam Theun 2 Hydroelectric Project

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**Professor Guy Lanza, PhD**
**Aquatic Ecologist/Microbiologist**
**Environmental Sciences Program**
**University of Massacheusetts, Amherst**

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## EXECUTIVE SUMMARY

The Nam Theun 2 Environmental Assessment and Management Plan (EAMP) lacks the essential balance that can only be provided by detailed site-specific baseline data sets and the use of appropriate models to help predict the impacts of the proposed project. The EAMP fails to accurately predict water quality impacts post-impoundment because it uses models calibrated with limited and insufficient data sets. The problems inherent in the Nam Theun 2 EAMP modeling approach are amplified by a trend toward a gross oversimplification of complex aquatic ecosystem structure and function. Entire groups of important ecosystem components (e.g. macroinvertebrates) are not included in the data collections or model assumptions.

The Nam Theun 2 Project is ecologically unsound and will cause serious and irreversible environmental damage to the area. The reports supporting the project are largely based on insufficient data and seriously flawed assumptions and methodology. Major findings from a review of the Water Quality section of Nam Theun 2's EAMP are as follows:-

- The severe reduction of flows and the elimination of natural flood events will produce major negative effects on the ecological integrity of the Nam Theun River ecosystem below the dam. Trapping large volumes of sediment in the reservoir basin will deprive downstream species of essential nutrients and produce excess levels of nutrients and toxic chemicals in the reservoir. The reservoir habitat will not replace the critical functions of the Nakai Plateau wetlands, affecting many species of birds and other important plant and animal species.
- The EAMP provides no data on aquatic macroinvertebrates. This is a serious omission, as macroinvertebrates play a vital role in establishing and maintaining good water quality and are an important source of food to many fish and other species.
- The report makes no mention of the rapid regrowth of vegetation and residual biomass from agricultural activities in the area that is likely to occur even if the biomass from the inundation area is removed. This residual biomass will likely lead to anaerobic conditions in the reservoir after impoundment, leading to a loss of macroinvertebrates, fish and other key biota in the reservoir and in the Xe Bang Fai after the start of power production.
- The EAMP fails to comprehensively examine the possibility for toxic blooms of cyanobacteria and algae in the reservoir. Toxic blooms of these microorganisms can produce severe sickness and mortality in humans, wildlife and livestock.
- The EAMP admits that the lower 6-8 meters of the reservoir will be anoxic during the dry season, but no mention is given to the cascade of serious negative impacts that will result, including fish kills and impacts to other essential organisms in the area.
- The potential for prolonged anoxia and resulting releases of nutrients and toxic gases in the Nakai reservoir will result in the loss of adult and juvenile fish and fish eggs. No effective mitigation strategies are offered in the EAMP.
- The reservoir will expand the habitat for vectors of major waterborne diseases known to inhabit the project site. Diseases such as malaria, dengue fever, schistosomiasis, and liver fluke can quickly spread, resulting in additional health risks for the resettled populations.

## BRIEF PROJECT DESCRIPTION

The proposed Nam Theun 2 project (NT 2) will create the Nakai reservoir using water from a trans-basin diversion of flow from the Nam Theun watershed to the Xe Bang Fai watershed. The completed reservoir will have a full supply level (FSL) surface area of 450 $km^2$ and will contain 3,910 million $m^3$ of water. The predicted FSL level of 538 m will result in a reservoir configuration that will be characterized by predominantly anoxic conditions, and prolonged periods of very low water quality and severely degraded biological habitat for fish and other important organisms. The severely degraded biological habitat created by the Nam Theun 2 project can result in a cascade of negative ecological effects that are clearly not compatible with good water resource management practices.

## PROBLEMS WITH BASELINE DATA AND MODELLING

**Major Finding:** The baseline hydrology data and the surface water quality data that is provided for the project area is extremely limited. It is clearly not sufficient either for use in estimating water quality changes in general, or for accurately calibrating water quality models. Specifically, the lack of adequate data available for the project area does not permit accurate predictions of the water quantity and quality changes that will occur in the proposed Nakai Reservoir, or the Nam Theun, Nam Kading, Xe Bang Fai, Nam Kathang, and Nam Phit Rivers. There is no evidence in the report that the basic requirements for completing accurate simulation models have been met, and that the water quality predictions in the report are accurate portrayals of what will actually occur during the construction and operation of the Nam Theun 2 project.

**Discussion:** Water quantity and quality are ecologically inseparable parameters; it is not possible to completely disaggregate one from the other as the authors do in the EAMP. Natural variations in water quantity and quality over time will simultaneously reflect patterns of precipitation, flow, discharge, and the physical and chemical character of water and sediment structure in rivers and lakes. The aquatic biodiversity of rivers and lakes is adapted to the natural patterns of both water quantity and quality as an aggregate in a specific geographic locale. The Nam Theun 2 project will produce severe changes in the natural patterns of water quantity/water quality in the region and beyond, and these changes will result in serious ecological damage.

The deficiency in water quantity data is covered in the Review of Hydrology for Nam Theun 2 by Dr. Peter Willing and Karla Knoop. The data used to characterize the baseline water quality in the project area is wholly inadequate. During the predominately dry season, there were only seven water quality samples collected, and these were apparently not replicated (i.e., they are single samples). The samples were taken during unevenly spaced time intervals with no data collected for approximate five-year time spans between 1990 and 2002.[1] Data for the predominately wet season is even more limited with only three samples total taken during a single year, i.e., one sample each for the months of May, September, and November of 2001.

[1] Specifically, in 1990, a single sample was collected from one locale during February and April; in 1995, a single sample was collected from one locale in March; in 1996, a single sample was collected from one locale in December; in 2001, a single sample was taken in April; and in 2002, a single sample was taken in March.

The summary of water quality in the Nam Theun, Nam Kathang and Xe Bang Fai provided in Table 3.20 (p.71) is also very limited in both quantity and scope. For example, only eleven parameters are listed and many of these consist of single measurements that are restricted to one collection site. The data was collected four years ago, and the value and accuracy of the measurements is compromised by the absence of data for some key parameters during the critical dry season period in the Nam Kathang and Xe Bang Fai rivers (i.e., suspended solids, calcium, magnesium). The authors are apparently well aware of the severe shortcomings of their data set since they state their intention of gathering additional data on page 70: "A monitoring programme starting early in 2004 will extend the existing baseline data and further the knowledge of water quality dynamics before the start of construction and operation."

The EAMP Main Text describes water quality changes that will result from the NT 2 project on pages 70-77 and Annex G1-G4. The authors claim that their analysis "presents the existing water quality data, and the potential changes in water quality, of the Nakai Reservoir, and of the rivers impacted, based on computer simulations for the reservoir and on a model of evolution of dissolved oxygen for the water released into both the Nam Kathang and the Xe Bang Fai." (p. 70). However, the specific details of their assumptions and the model outputs are not presented and are not available to outside technical review.[2] The baseline surface water quality data that is provided for the project area is extremely limited and clearly not sufficient either for use in estimating water quality changes in general, or for accurately calibrating water quality models.

The absence of detail from both the model calibrations and outputs make it impossible to determine if any of the "potential changes in water quality" are accurate. Most widely employed water resource models follow either a stochastic (random order) or a deterministic (particular order) approach. Stochastic models are seldom used because of the general lack of good *site specific* water quality data available for long enough time periods. In order to be useful, deterministic models require that the relationships between critical water quality parameters and the flow or hydraulic characteristics of the study site be accurately established, and that the appropriate biological and chemical functions be included. The use of models for predicting water quality impacts in reservoirs is especially complex because reservoirs have very different dimensions and flow characteristics when compared to streams and rivers (1).

The DYRSEM model which was used for Nam Theun 2 is a one-dimensional model that is based on many key assumptions that may not hold true for the Nam Theun 2 project design. For example, the model is based on the assumption that variations in movement in the reservoir in the vertical direction are more important than variations in the horizontal direction, an assumption that may not be accurate in many aquatic ecosystems. When considering the fact that surface winds strongly influence both the vertical and horizontal mixing patterns of rivers and reservoirs, the assumption raises many questions about the ability of the model to accurately simulate/predict the movement, mixing, and specific locale of critical substances in aquatic

[2] Attempts to access the reports referenced in the water quality section from Dr. Jason Antenucci of the Center for Water Research at the University of Western Australia were unsuccessful ( RE: Hydreco, 2001 a&b; Lewis, 1995; Jha et al., 1999; Prosser, 1997; Romero et al., 1999; Romero et al., 2000; Romero, et al., 2001; Winters et al., 1997). This reviewer was informed by email that "These reports were produced for clients, and we are not at liberty to distribute them without their permission. Hence, they are not available online." A request from IRN to NTPC was also rejected.

ecosystems. The vertical and horizontal movement of dissolved oxygen, nutrients, gases, and other important water quality factors (e.g., from top to bottom/bottom to top and horizontally across the aquatic ecosystem) might not be accurately described by the DYRESM – WQ model.

The model accuracy could be compromised further by the fact that cool temperatures in the mountainous watershed area (Annamite Mountains) will result in much cooler, denser and heavier water entering the reservoir, affecting the mixing and stratification patterns that are key to accurate models of aquatic ecosystems. Given the fact that no reliable project area data currently exists to compare to model predictions, the use of the model is questionable at best.

There is absolutely no evidence in the report that the basic requirements for completing accurate simulation models have been met, and that the water quality predictions in the report are accurate portrayals of what will actually occur during the construction and operation of the Nam Theun 2 project.

## SPECIFIC COMMENTS

### Altered Flow Regimes

**Major findings:** The severe reduction of flows and the elimination of natural flood events will produce major negative effects on the ecological integrity of the Nam Theun River ecosystem below the dam. Trapping large volumes of sediment in the reservoir basin will deprive downstream species of essential nutrients and produce excess levels of nutrients and toxic chemicals in the reservoir. The reservoir habitat will not replace the critical functions of the Nakai Plateau wetlands, affecting many species of birds and other important plant and animal species.

**Discussion:** The valuable and unique biodiversity of the river and its adjacent riparian zone and forested areas have evolved with the natural hydrological regime of the Nakai Plateau watershed. The array of different plant and animal species that occupy the habitat in the area is dependent upon specific flows of good quality water during critical time periods within and between seasons of the monsoon cycle. Naturally varying flow rates and water volumes regulate and sustain all of the critical river and wetland habitats. Specific flow levels and sudden increases in water volume and flow rate from periodic natural flood events replenish and maintain habitats by regulating water and sediment quality (e.g.turbidity, dissolved solids, suspended solids, temperature), providing substrate for attachment, protection from predators, nutrients for growth, adequate spawning/migration flows, and the mixing dynamics required for the essential biogeochemical cycles supporting the ecosystem.

Constructing a large reservoir in the Nam Theun watershed area will cause serious problems with the normal sedimentation patterns that support the entire river continuum, including the downstream sections of the Mekong River. The unrestricted movement and selective deposition of sediments are an essential natural component of the river systems. Sediment quality and quantity play a vital role in establishing and maintaining the natural architecture of the riverine and riparian habitats that are essential to the survival of the region's rich and unique biodiversity. Trapping large volumes of sediment in the reservoir basin will deprive downstream species of

essential nutrients and produce excess levels of nutrients and toxic chemicals (e.g. heavy metals, DDT) in the reservoir. The historical use of DDT in neighboring regions for mosquito control to reduce Malaria and Dengue Fever could introduce and concentrate this highly mobile toxic chemical in the sediments providing an entry point to the food web and biodiversity of the area. The turbining of large volumes of water can also create a sediment imbalance by selectively concentrating and rearranging the natural sediments both in the project area and downstream. Sediment habitat above and below the dam will also suffer from a loss of essential sediment replenishment.

The planned flow decrease to a weekly minimum of 2 $m^3$/s downstream of the Nakai Dam as a result of the trans-basin diversion of water from the Nam Theun river to the Xe Bang Fai river is a typical example of the extremely low flows that will produce irreversible ecological damage that cannot be mitigated. Riverine biota, riparian plant and animal communities, and migratory species will perish. The EAMP recognizes the fact that "The knowledge of the spawning and migratory behavior of fish species in the Nam Theun is limited" (p. 62), but offers no plan to deal with the threat.

Of equal concern are the negative effects from altering the hydrologic system during the wet season. The report acknowledges some of the damage likely to occur by stating that inundation of large areas of the Nakai Plateau wetlands during the creation of the reservoir will clearly magnify the negative impacts. The report then incorrectly implies that the reservoir has potential to compensate for the loss of wetland habitat. The distinct differences between wetland and reservoir habitats are well-established and reservoirs cannot provide habitat to replace the critical functions of wetlands. It is known that many species of birds use the Nakai Plateau wetlands, including the globally threatened white winged duck. Destruction of the wetland habitats will eliminate birds as well as many other important plant and animal species, and will substantially reduce the overall biodiversity in the region.

Ecological damage to the Xe Bang Fai river will also occur as a result of the trans-basin diversion of water from the Nam Theun River. The diversion will essentially reverse the normal dynamics of the river ecosystem continuum. The diversion will represent a major alteration to the normal pattern of the Xe Bang Fai river. Increasing the discharge 10-fold above the typical dry season level of approximately 20-30 $m^3$/s will produce severe negative impacts to the river biodiversity by damaging the natural structure and function of the river ecosystem. For example, significantly more erosion of the river banks and bottom areas will result and dramatically increase the normal transport and deposition patterns of sediments. Increased sediment transport and deposition will produce major negative impacts on the river habitat by causing increased turbidity that will result in decreased light penetration. Decreased light penetration will dramatically lower dissolved oxygen levels in the river by limiting the photosynthetic production of oxygen by microorganisms and plants. At the same time, increased oxygen demand due to elevated levels of eroded soil organic material in the river will further reduce dissolved oxygen levels. The decreased dissolved oxygen levels can also produce organism die-off that adds additional biochemical oxygen demand, further lowering oxygen concentrations. The key macrobiota that play an essential role in the processing and biogeochemical cycling of nutrients and other substances that maintain the river balance would perish.

Plans to re-oxygenate water prior to release to the Xe Bang Fai using weirs can help to add dissolved oxygen, but weirs require careful design and constant (=daily) monitoring and maintenance for the removal of debris that clogs and prevents effective re-oxygenation. And, maintenance workers will face considerable risk due to sudden river current fluctuations and related safety considerations.

Sediment distribution patterns in the river microhabitat will be altered with the clogging/filling of sites required for the feeding, reproduction, and other essential biological activities of macroinvertebrates, fish, and waterfowl. Aquatic biodiversity adapted to the normal wet/dry season dynamics of the monsoon cycles will also be affected by the abrasive effects of the increased load of suspended materials from the erosion of bank areas. Overall, the changes that will result from the "combination of weekly fluctuations in water level" (p. 31) will significantly lower the water quality in the Xe Bang Fai ecosystem.

**Biodiversity**

**Major finding:** The EAMP provides no data on aquatic macroinvertebrates. This is a serious omission, as macroinvertebrates play a vital role in establishing and maintaining good water quality and are an important source of food to many fish and other species. The complete absence of data on macroinvertebrate communities in the EAMP highlights the report's grossly oversimplified approach to environmental assessment.

**Discussion:** The EAMP description of the biodiversity of the Nakai Plateau region in the specific areas of the planned project lacks essential detail, and selectively emphasizes vertebrate species. One major flaw in the EAMP lies with the absence of site-specific data on the habitat and invertebrate species that are essential components of the aquatic food web. The lack of information on aquatic invertebrate biodiversity is typical of the oversimplified approach used in the report, and highlights a disturbing general trend in the EAMP that selectively disaggregates interacting components of the aquatic ecosystem for individual study while totally ignoring other essential components. For example, the EAMP provides some information on fish, mammals, birds, reptiles, and amphibians, but no data on aquatic macroinvertebrates is included.

Macroinvertebrate communities are routinely used around the world as a standard to measure and monitor water quality in aquatic ecosystems (2). Macroinvertebrate communities inhabit very specific microhabitats in different areas of streams and rivers (e.g. riffles and pools). They are essential components of global aquatic ecosystems that play a vital role in establishing and maintaining good water quality. Macroinvertebrates also provide an important source of food to many species of fish, amphibians, reptiles and birds.

The complete absence of data on macroinvertebrate communities in the EAMP highlights the report's grossly oversimplified approach to environmental assessment. For example, in discussing the impacts from the proposed trans-basin diversion of water (pages 30-31), the authors indicate that "The diversion of water from the Nam Theun to the Xe Bang Fai will dramatically alter the discharge regime in the Nam Theun downstream of the Nakai Dam and the Xe Bang Fai downstream of the Nam Phit." They then describe a vague sequence of oscillating levels of water diversion "up to a maximum of 330$m^3$/s" with "occasional" inter-basin transfers

as low as $30m^3/s$ or lower. Without biological data, it is not possible to accurately predict or even speculate on the environmental effects on macroinvertebrates or other biota due to the proposed altered flow regimes in the Nakai and Xe Bang Fai watersheds.

**Biomass**

**Major finding:** The report makes no mention of the rapid regrowth of vegetation and residual biomass from agricultural activities in the area that is likely to occur even if the biomass from the inundation area is removed. This residual biomass will likely lead to anaerobic conditions in the reservoir after impoundment, causing sediment releases of heavy metal contaminants, toxic gases (e.g., methane, hydrogen sulfide), nutrients, and severely lowered dissolved oxygen levels that will lead to a loss of macroinvertebrates and other key biota including fish in the reservoir and in the Xe Bang Fai after the start of power production.

**Discussion:** The casual treatment of biomass left in the inundation area in the EAMP is particularly troublesome. The report states that "NTPC will encourage the removal of biomass from the inundation area prior to flooding through firewood collection and the salvage of timber." No mention is made of the re-growth of vegetation that rapidly occurs in tropical ecosystems, or the impacts of residual biomass from agricultural activities in the area, particularly rice straw which can contribute to hydrogen sulfide generation that is highly toxic to fish and other reservoir biota (3). This reviewer visited the Nam Leuk reservoir basin in Laos after biomass removal, just prior to the period when it was filled with water. After biomass "removal", the site contained considerable amounts of tree debris, shrubs and new growth plant biomass that clearly set the stage for anoxic conditions after the reservoir was filled. The report clearly acknowledges the problems with biomass "removal" on page 78 where it states "Even after cutting and burning biomass before inundation, the Nam Leuk reservoir turned anaerobic, resulting in fish kills in the reservoir and downstream after the start of power production."

**Anoxia**

**Major finding:** The EAMP admits that the lower 6-8 meters of the reservoir will be anoxic during the dry season, but no mention is given to the cascade of serious negative impacts that will result, including fish kills and impacts to other essential organisms in the area.

**Discussion:** The report states that "periodic episodes of low dissolved oxygen (<2 mg/l) were predicted to occur in the deeper waters under thermally stratified conditions (Figure 3.41). Anoxic conditions generally lasted for one to three months, and because of the shallow nature of the reservoir these anoxic conditions affected less than 3 % of the reservoir volume." The report authors fail to point out that most of the Nakai Reservoir total area will be quite shallow (<10 m) with the potential for anoxic conditions in the water below the surface 2 meters. The "evolution of anoxic conditions in the bottom water" is acknowledged (p. 73), but no mention is given to the cascade of serious negative environmental impacts that will result from the anoxia, or the influx of nutrients that will result from the large amount of biomass that will be in place when the reservoir basin fills. It is important to note that the cascade of negative environmental impacts that will be triggered by prolonged periods of anoxia will not be limited to fish kills, but can also

cause irreversible ecological damage to other essential organisms in the Nakai watershed ecosystem. Some of the major negative environmental impacts are discussed below.

The EAMP authors assume, incorrectly, that the severe anoxia and related negative impacts are to be expected and are unavoidable events in new reservoirs. In fact, the number and duration of severe anoxic events in new reservoirs can be minimized by careful planning based on good pre-impoundment assessments. Reservoir planning experts have been suggesting the need for good pre-impoundment assessments for decades. In discussing tropical impoundments, Macgregor and Keeney (4) stated " In view of the remarkable number of impoundments possessing poor water quality, much more effort needs to be expended in predicting, before construction, the likelihood of producing a eutrophic body of water." One good approach to reduce the impacts of the initial flooding of a new reservoir is the careful removal of all surface vegetation and the removal of the litter and the soil A- horizon layers with their nutrients and organic oxygen-demanding substances just prior to filling. Another method involves the application of reservoir filling practices that mitigate against the harmful effects of sudden soil flooding and the decomposition of organic matter. Reservoir filling approaches that use seasonal timing of inundation, control of water levels, and the use of staged or incremental filling are very useful in lowering the impacts of excess nutrients that stimulate imbalanced microbial growth, and in lessening the extent of anoxia. (5)

**Toxic Blooms of Cyanobacteria and Algae**

**Major finding:** The EAMP ignores the current knowledge about the primary causes of toxic blooms of cyanobacteria and algae. The result is a high degree of uncertainty in the EAMP about the occurrence of toxic blooms of cyanobacteria and other nuisance microorganisms in the reservoir. Toxic blooms of these microorganisms can produce toxicity, severe sickness and even mortality in humans, wildlife and livestock.

**Discussion:** The toxic blooms of cyanobacteria are extremely important because they can produce toxicity and mortality in humans, wildlife, and livestock. The risk of "algal blooms and eutrophication causing abundant weed growth" is mentioned in an earlier report on the Nam Theun 2 project (6). Tables B.4-2 and B.4-3 of the earlier report list several types of cyanobacteria (*Anabaena* and *Oscillatoria )* that are known to produce potent toxins. Both types of cyanobacteria thrive in nutrient-enriched habitats and some species produce toxins that cause acute liver toxicosis, rapid neurotoxicosis, and severe forms of gastrointestinal illness. Recent reports from China have described chronic health effects from cyanobacterial toxins linked to drinking water. The reports indicated increased cancer tumor rates in humans exposed to hepatotoxic cyanobacteria-contaminated water (7).

Additional problems can occur as toxicity to animals drinking the water and/or ingesting cyanobacterial cells. Economically valuable livestock, pets, and important wildlife species including those on the IUCN threatened and/or endangered species lists could be placed at risk. And on page 48 the EAMP states that "The drawdown zone offers potential for the establishment and management of aquatic and other plant species for supplementary forage." However, the potential for contamination of the supplemental forage by cyanobacterial toxins and/or biomass is not addressed.

The authors of the EAMP choose to ignore the current water quality knowledge that helps to explain the induction of blooms of toxic cyanobacteria and algae, and persist in applying the oversimplified concepts of total quantities of primary nutrients (i.e., Nitrogen and Phosphorus) as a predictor of the possibility of bloom events (p. 70). While the quantities of specific nutrients are important, the specific ratio of one nutrient to another is a more significant indicator of the induction of toxic blooms. The levels reported, i.e., concentrations of Nitrogen (10-190 ug/l) and Phosphorus (less than 20 ug/l), indicate primary nutrient ratios well below the N/P ratio of 30/1 that is generally characteristic of a healthy reservoir system with a balanced microbial community that is not dominated by cyanobateria. The concentrations are in fact below 16:1 which can promote cyanobacterial blooms since many cyanobacteria can supplement their nitrogen requirements using nitrogen fixed from the atmosphere (8).

Perhaps more importantly, the water quality models that are a central part of the EAMP analyses cannot predict qualitative changes in complex aquatic microbial communities; i.e., the models cannot tell which species of cyanobacteria or algae will appear at a particular concentration of a nutrient or nutrient-temperature scenario. The EAMP authors clearly acknowledge the high degree of uncertainty in their predictions under "Results of the Water Quality Model" on Annex page G-3 where they state: "This is not to say *a priori* that blue-green algal blooms will occur in the Nakai Reservoir, as undoubtedly the local species of diatoms, green algae, and other algal groups in the Project catchment are likely to adapt to high temperatures. However, if nitrogen is the limiting nutrient, blue-green algae may be dominant during the summer months when river inputs are low."

**Toxicity to Fish**

**Major finding:** The potential for anoxia and resulting releases of nutrients and toxic gases in the Nakai reservoir will result in the loss of adult and juvenile fish and fish eggs. No effective mitigation strategies are offered in the EAMP.

**Discussion:** High oxygen demand at the sediment water interface will disrupt the protective barrier provided by the oxidized benthic microzone and result in the release of nutrients and toxic gases (hydrogen sulfide and methane) bound in the sediments. We predicted increased hydrogen sulfide and methane production triggered by anoxia in an earlier report describing the Nam Leuk project prior to its completion (9). Hydrogen sulfide is extremely toxic to fish and other aquatic biota. The Nam Theun 2 EAMP acknowledges the prospect of hydrogen sulfide and methane generation as a result of building and operating the project. The report also clearly acknowledges the fact that the hydrogen sulfide problem we predicted earlier already exists in the Nam Leuk reservoir, stating on page 73: "In 2001, water quality problems continued to exist at the Nam Leuk reservoir impounded in 1999. The reservoir is anoxic from a depth of approximately 10 m to the bottom of the reservoir. Discharge from the power station indicates ferric oxidation and at times there is an odor of hydrogen sulfide. In the dry season, the water discharged from the power station is almost anoxic with less than 0.5 mg/l of dissolved oxygen and a fairly high concentration of dissolved methane (5 mg/l)." Methane production in the anoxic sediments and water will not only add to the toxicity to fish caused by low dissolved

oxygen and hydrogen sulfide, but will also contribute to global climate change by adding to the greenhouse gas pool.

The increased nutrients released from the sediments can introduce qualitative changes in water quality that will favor the growth of undesirable species of algae and cyanobacteria, and quantitative changes in biomass that can remove additional oxygen from the water column. Together, the cascade of oxygen depletion, hydrogen sulfide poisoning, toxic microbial blooms, and fish spawning mortality will cause irreversible damage to the water quality and aquatic biodiversity of the valuable and unique Nakai Plateau ecosystem. Our earlier review of the Nam Leuk reservoir environmental assessment plan prior to its completion predicted a similar pattern of negative environmental impacts, many of which were later documented on-site (9). Similar environmental impacts are cited in the current Nam Theun 2 EAMP, but no effective mitigation strategies are offered.

The loss of fish as an important ecological species and as a major source of protein for local populations can lead to increased exploitation of the biodiversity in the area. A recent report describes the direct link between decreased fish supply and increased hunting pressure on animals to provide wild meat in local markets (10). Using data from a thirty year period, the authors demonstrate that periods of poor fish supply coincided with increased hunting pressure in nature reserves in Ghana that led to sharp declines in forty-one wildlife species. Local market data provided evidence of a direct link between fish supply and increased hunting pressure on animals used for wild meat. Finally, the potential for introducing new patterns of human disease as a result of contaminated wild meat entering village and urban markets adds to the negative impacts of decreased fish supply (11).

**Public Health/Waterbourne Diseases:**

**Major finding:** The reservoir will expand the habitat for vectors of major waterborne diseases known to inhabit the project site. Diseases such as malaria, dengue fever, schistosomiasis, and liver fluke can quickly spread, resulting in additional health risks for the resettled populations.

**Discussion:** Although the reports describe the public health needs in the region, it is not clear how the project will drastically improve the situation for the people in the project area. The report does not offer any details or general strategies to deal with increased water-related disease. However, the construction of the reservoir, the drastic changes in the flow regime that will vastly increase low-flow water conditions, and the construction of irrigation channels, will clearly enhance the breeding habitat for mosquito vectors of Malaria and Dengue Fever. Increases in mosquito vectors would lead to additional spraying of DDT or other toxic chemicals, which would be a threat to the biodiversity in the area.

Construction of the reservoir could also significantly increase the transmission of snail-vectored diseases in the area. Transforming the river system to a reservoir will optimize the habitat for many snail vectors of medical importance. In an earlier report on the Nam Theun 2 project, we noted the possibility of the presence of *Neotricula aperta,* the snail vector of *Schistosoma mekongi* in the general project area (12). Since that report, the results of a field survey of aquatic snails in the Nam Theun 2 project area listed 10 species of snails that are medically important or

of potential medical importance, including substantial numbers of *N. aperta* and *Bithynia s. goniomphalos*, the vector of liver fluke disease. The latter snail vector showed a high level of disease infection, i.e., 25 percent of the snails were positive for up to 7 different parasitic diseases (3). Liver fluke disease is a major public health problem in Southeast Asia, and extending the range of infection by optimizing the vector habitat is unacceptable (14).

The survey report recommendations include the statements "Environmental health engineering and environmental management is an important step at each project phase, in order to control any health hazard associated with this snail-borne disease." And, "More information on the ecological and quantitative aspects of snail distribution needs to be done through an extensive snail survey." Unfortunately, both critical recommendations are not directly addressed in the EAMP. The EAMP merely mentions in passing the potential of the waterborne diseases to increase as a result of the project and briefly outlines 'monitoring/mitigation' plans to address the serious public health threats.

## CONCLUSIONS

The Nam Theun 2 EAMP is technically flawed and lacks the essential balance that can only be provided by detailed site-specific environmental data sets and the use of appropriate models to help in the prediction of the environmental impacts of the proposed project. The EAMP is not based on high quality site specific data, and fails to accurately predict and/or characterize environmental impacts on water quality because it uses models calibrated with limited and insufficient data sets. The problems inherent in the Nam Theun 2 EAMP modeling approach are amplified by a trend toward a gross oversimplification of complex aquatic ecosystem structure and function. Entire groups of important ecosystem components (e.g. macroinvertebrates) are not included in the data collections or model assumptions.

The recent experience with the Nam Leuk hydroelectric project in Laos provides ample proof of the serious water quality degradation that results from ill-conceived water projects like the Nam Theun 2. Many of the predictions of negative environmental impacts made prior to the construction and operation of Nam Leuk have since proved to be accurate (11).

Eliminating unique habitat by creating dam projects and other barriers that restrict the migration of threatened species and that reduce and/or eliminate flowing river basins is not a method to preserve biodiversity. The loss of fish populations that will most certainly result from both the elimination of riverine habitat and the toxicity from lowered water quality in and below the planned Nam Theun 2 reservoir is not acceptable. The Nam Theun 2 Project will also inundate essential riparian and wetland habitat and will produce the crowding of species into areas too small or too damaged to support continued reproduction and survival. The loss of fish as an important ecological species, and as a major source of protein for local populations, can lead to increased exploitation of biodiversity in the area.

In summary, I am convinced that the Nam Theun 2 Project is ecologically unsound and will cause serious and irreversible environmental damage to the area. The reports supporting the project are largely based on insufficient data and seriously flawed assumptions and methodology.

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