FLOOD CONTROL CHALLENGES FOR LARGE HYDRO-ELECTRIC RESERVOIRS

Examples from the Nam Theun - Nam Kading Basin, Lao PDR

MK3

Optimising cascades of hydropower

HYDROLOGY & FLOOD CONTROL

August 2013

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Produced by	*Mekong Challenge Program for Water & Food Project 3 – Optimising cascades of hydropower for multiple use* Lead by ICEM – International Centre for Environmental Management
Suggested citation	Peter R.B. Ward, Timo A. Räsänen, PJ Meynell, T. Ketelsen. 2013. Flood control challenges for large hydroelectric reservoirs: Nam Theun-Nam Kading Basin, Lao PDR. Project report: Challenge Program on Water & Food Mekong project MK3 "Optimizing the management of a cascade of reservoirs at the catchment level". ICEM – International Centre for Environmental Management, Hanoi Vietnam, 2013
More information	www.optimisingcascades.org | www.icem.com.au
Image	Cover image: Srisailam Dam, Thailand. Inside page: The spillway of the Theun Hinboun diversion. In September 1996 the right bank abutment (left of photo) was severely damaged by a major flood, and was rebuilt at a higher elevation (photo credit: P. Ward)
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Acknowledgements	Information and ideas for this project were collected during a site visit by the team in 2011. We would like to acknowledge co-operation from Theun Hinboun Power Company, Nam Theun 2 Power Company, Nam Theun Nam Kading River Basin Committee Secretariat, and Nam Theun 2 Watershed Management and Protection Authority. Long term daily flow data at TH dam and other sites were kindly provided by Theun Hinboun Power Company, as was information about the current state of flood management. Rainfall data were from Mekong River Commission Secretariat sources. Funding for this project was from the Mekong river component of the CGIAR Challenge Program on Water and Food.

SUMMARY

Large hydroelectric reservoirs can be used to reduce inundation downstream. Factors related to regional climate are important in determining the likelihood of successfully operating the reservoirs for flood control, and the operator must have adequate advance notice of extreme weather events. In boreal climates that are dominated by a combination of snow melt and rain, it is possible to achieve a degree of predictability about expected flooding, based on information about snow pack accumulation. This information is available many weeks before the onset of melt conditions, and allows adequate time for flood preparedness. Reservoirs in tropical climates present more challenging conditions for flood control.

In the Nam Theun Nam Kading River Basin, seasonal rainfall events are determined mainly by the Western North Pacific monsoon. Tropical cyclone events such as typhoons and tropical storms vary each year in their strength and number. In some years they make major contributions to rainfall and runoff in the basin. Most events that cause extreme flooding in the basin have their origin in tropical cyclones, and sometimes these events are spaced no more than a few days apart. Several hundred millimetres of runoff can occur over several days, causing massive floods in the tributaries and mainstream river.

The challenge for designers and operators of hydroelectric reservoirs is to predict events well enough to ensure successful flood control. Spillway design is sometimes compromised by inadequate information, such as the availability of river flow information for the few years prior to project initiation. Climate change has been documented as a factor in causing long term shifts in weather, particularly in contributing to increased interannual extremes. Timeliness is the essence of flood control, and the difference of just one to two days in responding to the onset of a major flood can make the difference between safe and unsafe operation of the reservoir.

We present an example from Nam Theun 2 reservoir, using runoff values from the 2002 season, and assuming that the dams that contain the reservoir were built at that time. A combination of mechanical failure (one spillway gate at Nam Theun 2 dam not operating), and human/management error (a one-day late response) is shown to trigger water level conditions that constituted an extreme hazard. In contrast, the timely opening of spillway gates, combined with capability to release water from all gates at full capacity, allowed for reservoir levels to stay well within the safe elevation range, significantly reducing downstream flood discharge.

Suggestions are made to strengthen capacity of the NT-NK River Basin Committee Secretariat for emergency communications between dam operators and downstream stakeholders, and for periodic, long-term engineering assessments concerning safe reservoir operations. The ongoing research work on climate periodicities in the Mekong region is encouraging, as it promises to offer ways to achieve advance notice of the likelihood of an extreme weather season.

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1 INTRODUCTION

Flood control is one of the advantages to creating major water storage reservoirs on rivers. This is frequently cited as an additional benefit from reservoirs built mainly for hydroelectric power generation. The usual strategy is to use water storage in the reservoir to reduce the peak of the flood hydrograph, and release water several days or several weeks later, once the flows are receding.

The challenge of doing this successfully depends on engineering design, strategy (the seasonal planning for water level management at the reservoir), and to tactics (the day-to-day or hour-to-hour response by the dam operator during the flood event. Engineering calculations and design are extremely important, as well as the knowledge of the design team, and their ability to predict major flood events is crucial.

Once a dam has been successfully operating for a few decades, the downstream inhabitants become used to the new flow regime. Buildings and other infrastructure are sometimes constructed in floodplain locations that would have been hazardous in the decades prior to dam construction. Operators of upstream dams are under an obligation, if possible, to keep flows released from the spillway to a modest size, to avoid inundating downstream inhabitants.

Flood management in reservoirs involves engineering design that takes into account the largest flow events that the incoming river will produce in the future. Spillway gates are designed to be sufficiently large to allow exceptionally large floods to pass. For reservoirs with large surface areas, the design provides short term storage in the upper part of the reservoir profile, to allow for outflows that will for a short period (such as a few days) be smaller than the inflows. This achieves reduction of peak floods in the downstream river, compared with the pre-dam situation.

Dam operators must adhere to requirements for successful operation during floods. For reservoirs that are contained by earth dams and earth saddle dams it is particularly important that water levels are kept sufficiently far below the overtopping water level, because overtopping may result in erosion of the dam wall and subsequent catastrophic failure. Achievement of safe water levels involves:

i. holding the reservoir at a sufficiently low level during the lead-up to the main flood season so that there is storage room to spare
ii. timely release of water through the spillway, with the ability to open all spillway gates to their maximum.

Large dams worldwide exist in climate zones with fundamentally different hydrological characteristics. In much of the North American continent and many parts of Europe, for example, most major rivers are driven by a climate that is characterized by a combination of snow melt events with rain during the spring/early summer period. Advance notice about the severity of flooding from the snowmelt component may be obtained reliably well in advance by snow pack surveys.

Near the end of the snowmelt runoff season, the dam operator gains confidence about future outcomes. The operator may become aware that there is no more snow left to contribute to river flows, and that only heavy rainfall will contribute to runoff. Experience in previous years adds to the body of knowledge. Short-term weather forecasting may indicate good weather for the next synoptic period. At this point the operator may decide that it is wise to allow the reservoir to rise above the normal full supply level to the emergency flood storage range, in the interests of minimizing downstream flooding.

During the 2012 snow melt season, for example, it was possible to reduce the maximum daily flow into the Koocanusa reservoir on the Kootenai River (United States/Canada) from 2,130m^3/s to 1,360m^3/s at Libby Dam in Montana, despite a well-above average snowpack, and summer rainfall that was unprecedented. The basin area at Libby Dam is 23,300 km^2 and comprises high altitude areas that provide mainly snow-melt and lower areas that provide snow melt and rainfall runoff. The river is a major tributary of the Columbia River.

Hydropower companies in the Columbia basin in Canada and the US control flows from their reservoirs in a coordinated way, to achieve the best level of flood control downstream. Flood control each year is done under the terms of the Colombia River Treaty, ratified in 1964, for the benefit of both countries. At Libby Dam, one of four dam sites included in the treaty, this involves an established strategy for provision of adequate storage room for floods, an early season pre-spill at the dam, access to timely data on snow pack levels, and use of short term rainfall forecasts. Operators may use some of the emergency storage volume (120 Mm^3) above the normal 'full supply' level, for flood control. In 2012, the reservoir was held near this very high level for a period of 26 days, to ensure that downstream flows were not extremely high, and infrastructure downstream (in both USA and Canada) was not damaged.

For large reservoirs in high rainfall tropical climates such as in the Nam Theun Nam Kading (NTNK) Basin, there is modest inter-annual variability of annual rainfall, combined with extreme variability of multiday synoptic cycles, associated with heavy rainfall following typhoons. One season may produce one or more rainstorms that are many times more intense than any storm experienced in the previous decade. Such events may be caused by conditions such as two typhoons that are close to each other in time and position.

Many years may pass before there is a 'hit' on the river basin. The resulting extremely large runoff may produce river flows beyond the memory of downstream inhabitants, with accompanying damage to infrastructure. Operational procedures for flood management can be tested and refined only rarely, providing challenges for emergency preparedness and communications.

A river basin such as the NTNK basin is characterised by a number of existing and proposed reservoir storage projects that are either in the mainstream river, or in tributary basins. Within the basin there is also large spatial variability, as discussed in the next section. In this case it is important that flood management activities in the reservoirs are operated in unison, depending on the location of extreme rainfall, to mitigate downstream flooding. The best possible communication is needed between the operators of the various dams, within agreed guidelines that have been thought through in advance.

In the next sections, we will explain the nature of the runoff characteristics of the NTNK basin, with a modelled example of how the major flood of 2002 may have been managed, had the Nam Theun 2 project been constructed at that time.

2 NAM THEUN-NAM KADING BASIN

2.1 BASIN LOCATION AND MAIN GEOGRAPHICAL CHARACTERISTICS

The Nam Theun-Nam Kading (NTNK) basin is a sub-catchment of the Mekong Basin, located in Central Lao PDR in the Bolikhamxay and Khammouane provinces. It has a total catchment area of 14 890km^2 (Figure 2-1). The catchment is bordered in the northeast by the Annamite mountain range, where many of the tributaries of NTNK River also originate. The distance from the crest of this range to the Vietnam coast is short, about 60 to 70 km. The highest peaks in the catchment are 2000masl and the lowest point is 150masl in the western part of the catchment, where the NTNK discharges its waters into the Mekong River.

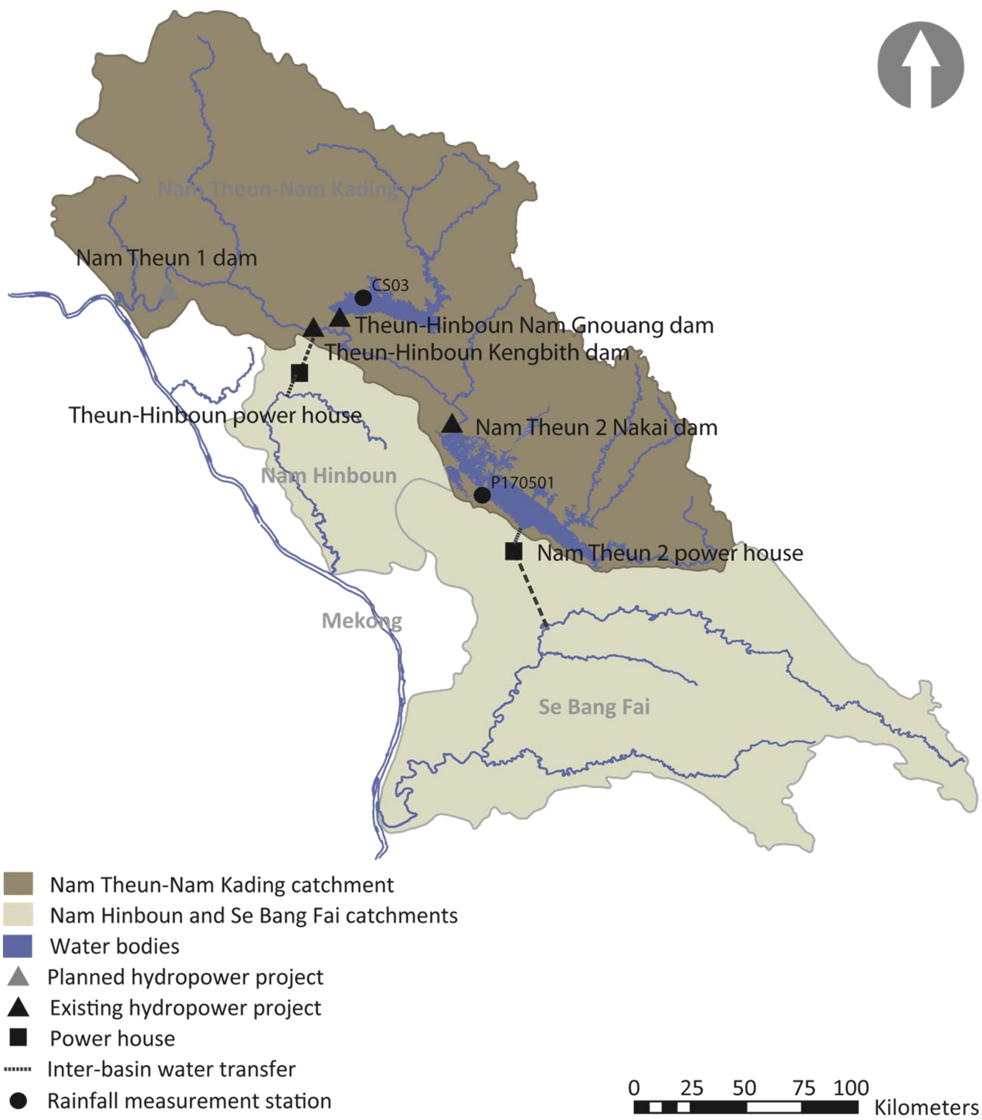

Figure 2-1: Nam Theun-Nam Kading basin, dams and inter-basin diversions. *Water is transferred to Hinboun and Se Bang Fai Rivers via the hydropower projects. The Mekong River, flowing south, is shown on left of figure*

2.2 CLIMATE

The climate in the lower Mekong Basin is dominated by a monsoon period with distinct wet (May-Oct) and dry seasons (Nov-Apr). The beginning of the wet season is marked by the onset of the South West Monsoon and later in the wet season the tropical cyclones start to bring rainfall into the region from the South China Sea (MRC, 2005). The dry season is mostly affected by drier air from the northeast. The clear distinction between wet and dry seasons has also created river flow regimes with a monomodal flood pulse (Junk et al., 2006). The region where NTNK lies is one of the wettest regions in Lao PDR and in the entire Mekong Basin. The annual rainfall in NTNK, of which great majority falls in the wet season months, can vary from 1,800mm to 3,200mm (MRC, 2005). However, the rainfall within the NTNK catchment can vary greatly, as shown by data from three rainfall stations in different locations (Figure 2-2).

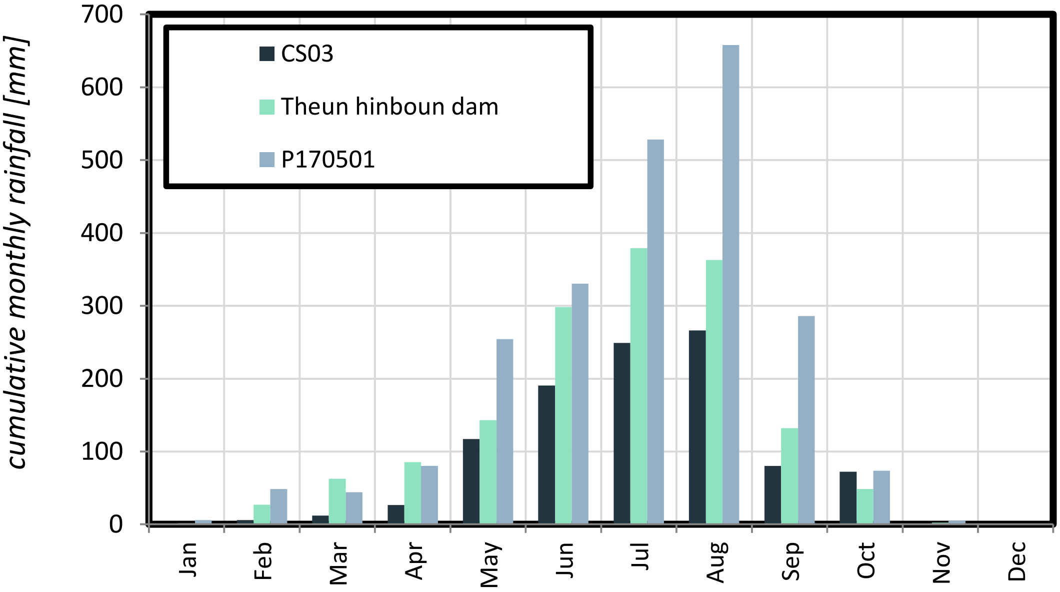

Figure 2-2: Average of monthly rainfall of three measurement stations in NTNK catchment from the period 2003-2007: *The average annual rainfall of the three stations was respectively 1020mm, 1543mm and 2315 mm (see locations in Figure 1).*

2.3 HYDROPOWER PROJECTS IN THE NTNK BASIN

Currently three hydropower projects exist in the NTNK basin: Theun-Hinboun hydropower project (TH), Nam Theun 2 hydropower project (NT2) and Nam Gnouang hydropower project (NG) (see locations in Figure 1). The TH and NG are operated by Theun-Hinboun Power Company (THPC) and the NT2 by Nam Theun Power Company (NTPC).

The first dam, Theun-Hinboun, was commissioned in 1998 and is the most downstream dam of the three dams in the Nam Theun River. The dam is modest, with installed capacity of 210 MW; it holds back a reservoir of small volume, so there is little possibility for flood control. The TH is an inter-basin transfer project where the water intake for turbines is in Nam Theun River Basin and the outlet is in Nam Hinboun river basin. In 2012 another set of generating units is being installed, doubling installed capacity.

The second dam, Nam Theun 2, was commissioned in 2010 and is located upstream of TH in Nam Theun River. The installed capacity of the NT2 project is 1,090MW. NT2 is also an inter-basin transfer project; the water intake is in the Nam Theun basin and the outlet is in Se Bang Fai river basin. The reservoir has a large volume and surface area, providing good prospects for flood control, provided adequate advance warning about the onset of intense rain is available.

The third dam, Nam Gnouang, was completed in 2012. It is located in Nam Gnouang tributary, which enters the Nam Theun river between the TH and NT2 dams. The NG was designed primarily as a storage project, and includes modest energy production (60 MW peak power) at the dam. The reservoir will be used to feed water to the downstream hydropower project, TH. Spillway capacity is very large, and major release flows in the future will have to be well planned and coordinated, to avoid severe downstream flooding. Technical details of the hydropower projects are presented in Table 1, and photos of spillways for two of the projects are shown in Figure 2-3.

Table 1: Main characteristics of Theun-Hinboun, Nam Theun 2 and Nam Gnouang hydropower projects

	Theun-Hinboun*	Nam Theun 2**	Nam Gnouang
Dam height *[m]*	27	39	67
Active storage *[mcm]*	15	3530	2260
Flood buffer *[m]*		1410	470
Reservoir drawdown *[m]*	5	12.5	35
Surface area at FSL *[km2]*	6.3	450	107
Average discharge *[m3/s]*	220 (460 before NT2)	240	95
Catchment area *[km2]*	8937	4013	2942
Installed capacity *[MW]*	210 to be enlarged	1090	60
Head *[m]*	230	348	47
Turbine discharge *[m3/s]*	110	330	144
Annual production *[GWh]*	1356 (1645 after NG)	5936	294
Spillway type	2 radial gates (1160m^3/s/gate); 1 flap gate (50m^3/s); 4 sand flushing gates (20m^3/s/gate); fixed overflow weir	5 radial gates (1374 m^3/s/gate); 2 flap gates (192m^3/s/gate)	5 radial gates (3144 m^3/s/gate)
Spillway capacity *[m3/s]*	12500	6870	15700

** Data from Then-Hinboun are before the 2012expansion project.*
*** Data are for Nakai Dam on Nam Theun River. Reservoir is also contained by (earth) saddle dams, on the south side.*

Figure 2-3: Dams and spillways for the NTNK Basin: *(left) Nakai dam of Nam Theun 2 Reservoir (source: Power Technology, 2012); (right) Nam Gnouang dam*

3 DATA AND METHODS

3.1 DATA

Data on the rainfall, discharge and hydropower project characteristics were provided by Theun-Hinboun Power Company, Nam Theun 2 Power Company and Mekong River Commission. The rainfall data included three stations: Theun-Hinboun dam site, CS03in Nam Gnouang catchment and P170501 in Nam Theun catchment upstream of Nam Theun 2 Nakai dam (see locations in Figure 2-1). The discharge data included daily discharge from Theun-Hinboun dam site (August 2002-October 2011), CS03 (May 2007-May 2010) and from Nam Theun 2 Nakai dam site (January 2003-December 2005). The data from Theun-Hinboun dam site was based on water balance calculations at the reservoir where different water balance components (reservoir volume, turbine discharge and spillway discharge) were accurately defined. The hydropower project characteristics data in Table 1 were collected from various datasheets and manuals provided by the power companies. The study also looked at tropical storm occurrence in the study region; the tropical storm data was obtained from IBTrACS storm tracks database (Knapp et al., 2010).

3.2 RESERVOIR MODEL

A spreadsheet model with daily time steps was developed to simulate the flood operations at Nam Theun 2 reservoir. The model was based on the simple water balance equation:

$$Q_{inflow} + Q_{turbine} + Q_{Spillway} = \Delta S \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$ [1]

where:

Q_{inflow} is the natural daily inflow [Mm^3],
$Q_{turbine}$ is the daily discharge through turbines [Mm^3],
$Q_{Spillway}$ is the daily discharge through spillway gates [Mm^3] and
ΔS is the daily change in reservoir storage [Mm^3]

For Q_{inflow} into NT2 we used an example flood constructed from the measured flood of 2002 at the TH dam site. The measured discharge was scaled using the ratio of annual mean runoff at NT2 and TH dam sites. The resulting time series for NT2 reservoir simulation was from the beginning of June till the end of October. The $Q_{turbine}$ was kept constant at 19 mcm/day, corresponding to the daily mean for the scheduled NT2 power plant operation of 16 hours a day, at full turbine load.

In the simulation, the reservoir storage was divided into two parts: active storage and emergency flood storage. The active storage was set to the full supply level (538 masl) and the flood emergency buffer from that elevation to 0.5m below the dam crest level (541.5masl). The volume of the flood emergency buffer was estimated from the elevation-volume data of the active storage by fitting a third order polynomial function to known data and extrapolating the elevation-volume up to the dam crest.

4 RECENT FLOOD HISTORY

4.1 FLOW REGIME ANALYSIS

The flow regime of the NTNK River has an annual cyclical nature, where the dry season flow is low and the wet season flow is high (Figure 4-1). For example, the average annual discharge at the Theun-Hinboun dam site is 364m^3/s. This average discharge is characterized by the lowest and highest monthly average discharges of 53m^3/s (in April) and 1130m^3/s (in August). Thirty percent of the

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[1] *Note that evaporative losses are omitted from the equation, as the time scale for computing the water balance is short, and the relative magnitude is very small*

annual flow occurs during the dry season and 70% in the wet season. Twelve month duration runoff volumes for the data set show a relatively low coefficient of variation of about 24%, a value that relates to the large annual unit area runoff of the basin (1623 mm/y at Theun Hinboun dam based on Table 1).

According to the annual average discharge at dam sites (Table 1) and their respective catchment area (Table 1), the annual runoff varies within the NTNK basin, suggesting local changes. The annual average runoff from catchment areas above NT2 and NG was 1,886mm and 1,018mm respectively. The catchment area above NT2 is therefore considerably wetter than the catchment area above NG. The annual average runoff from the TH catchment, which contains both NT2 and NG catchments, was 1,623 mm.

The daily discharge data at the Theun-Hinboun dam site (Figure 4) shows that the wet season contains commonly several flash flood events of different magnitudes, suggesting that the rainfall-runoff response in the catchment is fairly rapid. A feature in the discharge time series is that towards the end of the wet season, a separate large, distinct, short duration flood peak can be observed in six out of ten years. These flood peaks occurred between the dates 19th of September and 17th of October.

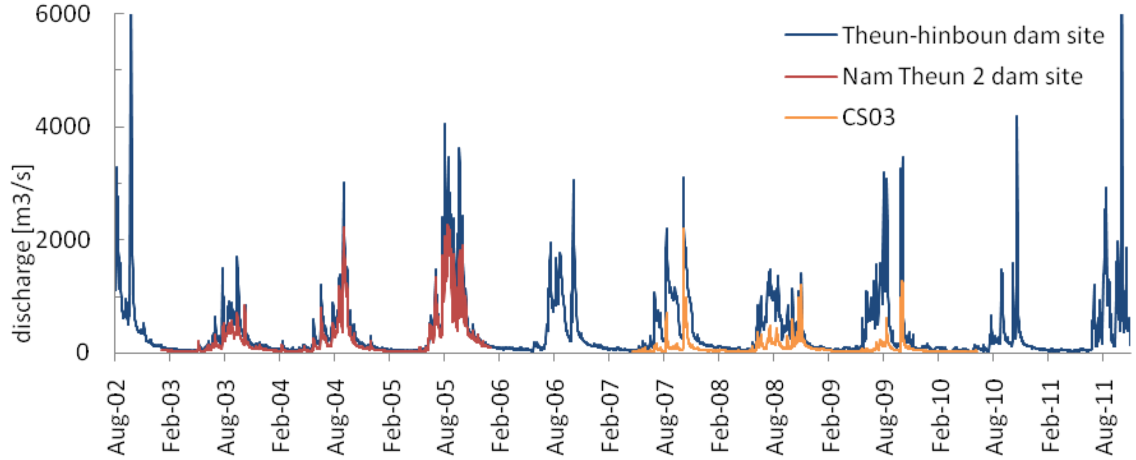

Figure 4-1: Ten year variability in daily discharge at three NTNK stations: *the full magnitude of flood peaks in September 2002 and October 2011 are not shown above and displayed in fig. 5-2.*

Recent major flood peaks occurred in September 1996, September 2002 and October 2011 (Figure 4-1 and Figure 4-2). The 1996 flood event was caused by exceptionally wet weather related to a typhoon (THPC, 2003). Damage at the TH dam caused the Theun-Hinboun Power Company (THPC) to subsequently increase the height dam abutments, piers and barrier walls of the Theun-Hinboun dam (THPC, 2003). Unfortunately no discharge data were available from the 1996 event for our study. The 2002 event was an extremely high flood event, lasting for 5-7 days and had a peak flow of 19 000m^3/s at the Theun-Hinboun dam site. The associated runoff was most likely caused by exceptionally wet weather following a typhoon, evidenced by the typhoon tracks shown in Figure 6.

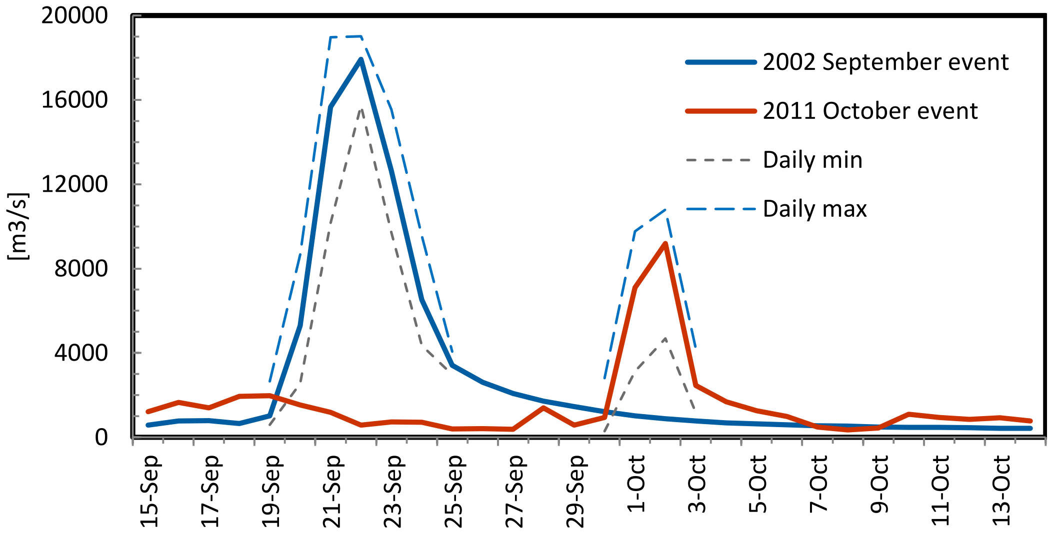

Figure 4-2: The discharge at Theun-Hinboun dam site during the 2002 and 2011 flood events: *The continuous lines show the daily average discharge and the dashed lined show the hourly minimum and maximum discharges. The 2011 event was likely affected by storage in NT2 reservoir, compared with flows that would have happened without the project*

4.2 ANALYSIS OF RECENT FLOODS

The most recent significant flood event occurred in 2011, a serious flooding year for larger areas in the Mekong basin (MRC, 2011). The actual magnitude of the 2011 flood event is unknown, as the Nakai dam of the NT2 reservoir upstream of Theun-Hinboun dam was closed in 2009 and the reservoir may have attenuated the flood peak. Flow data from the TH dam site showed that the flood of 2011 was a four-day event with a peak flow of 10 790m^3/s (Figure 4-2). During the 12-day period 23rd September to 5th October 2011, tropical storm Haitung, preceded by typhoon Nesat, caused about 600 mm of rainfall in coastal Vietnam, and almost certainly accounted for the extremely high rainfall in the NTNK basin. Typhoon tracks during this period are shown in Figure 4-3.

The recent flood history suggests that the NTNK basin is prone to significant flood events with recurrence interval of 6-9 years. A general feature of the 1996, 2002 and 2011 flood events is that they occurred late in the wet season around late September-October, coinciding with a period of intense tropical cyclone activity. The passage of smaller events, such as tropical storms, can cause extremely serious flooding if they stall for periods of time over the basin.

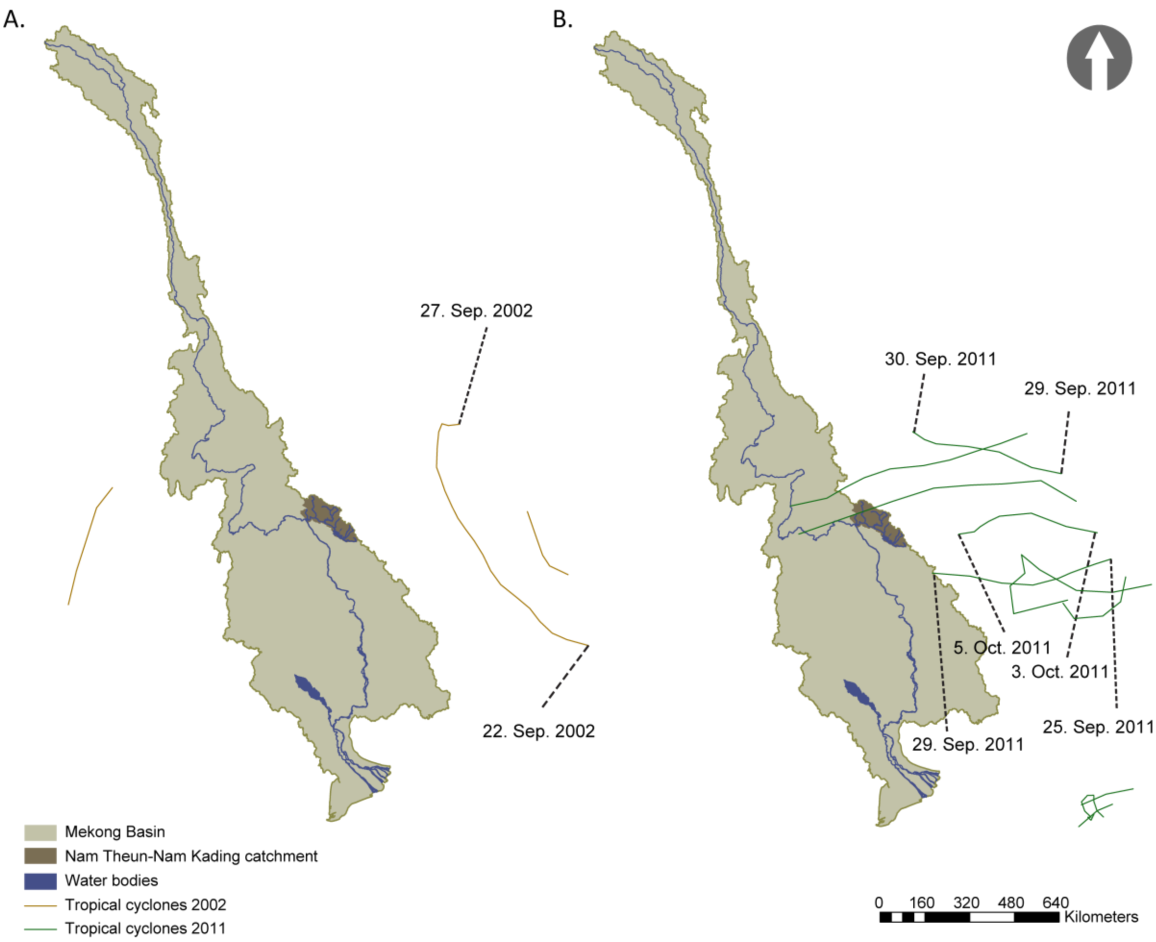

Figure 4-3: Mekong basin, typhoon tracks for year (a) 2002 and (b) 2011: *NTNK sub-basin is highlighted brown on the east side. The cyclones which occurred approximately during the September 2002 and October 2011 floods are marked with dates. Note that these tracks are for the centres of the typhoons only, and bely the huge areal extent of the atmospheric events. Only cyclone tracks which are within 500km distance from the Mekong Basin are shown*

5 OPERATION FOR FLOOD CONTROL

5.1 SIMULATION RESULTS

We provided the spreadsheet model (equation 1) with an estimated initial reservoir volume on 1st of June, and then adjusted the operation of spillway gates on a daily basis for the subsequent days of the flood season. We observed the filling rate of the reservoir according to the inflows, and the timing and opening extent of the spillway gates during the example flood event. Two scenarios were tested using the 2002 season inflow hydrograph:

A. Normal operation (satisfactory scenario)
B. Human and mechanical error(unsatisfactory scenario)

In scenario A, the assumption was made that all spillway gates were working, and none of them were partially blocked by debris. Discharge of water via the turbines continued for the whole duration. Adjustments to the gates were made in a timely way, according to the following schedule (see Table 2).

Table 2: Procedure for opening spillway gates of Nakai Dam for example flood under scenario A. Normal operation (satisfactory)

Date	Spillway gate opening
1st Jun-14th Aug	Spillway gates closed, release from reservoir only via turbine discharge
15th Aug	Fractional opening of one gate to allow discharge of 300 m3/s. Maintenance of reservoir level at approximately full supply elevation
20th Sept	Major rainfall event starting. Release flows equal to inflows, via gates
21st - 23rd Sept	Crest of major inflows. Open all 5 gates to full capacity (7000 m3/s)
24th Sept	Inflows declining. Keep 4/5 gates fully open to return res level to FSL
25th Sept	Inflows declining. Keep 3/5 gates open to return res level to FSL
26th-27th Sept	Inflows declining. Keep 2/5 gates open to return res level to FSL
28th-30th Sept	Inflows declining. Keep 1/5 gates open. Reservoir is returned to FSL
1st - 3rd Oct	Inflows declining. Keep one half gate open. Allow slight bounce back to FSL
4th October on	Gates closed. Reservoir surface stays close to FSL for several weeks

Scenario A was regarded as successful, as the surface level of the reservoir remained within a good margin of safety (see Figure 5-1). During the event the reservoir storage absorbed the peak flood, with the water surface rising within the flood emergency storage, and stayed well inside the volume of 1400 Mm^3 that is allocated for emergency storage.

The duration of this fill above the reservoir full supply level was about 10 days. Note that it was essential for dam safety reasons that the reservoir level **was at or below the full supply level on the days prior to flood arrival,** as the spillway capacity as designed was insufficient to pass the maximum inflow discharge without a significant rise in reservoir water surface. The outflow peak discharge (7000 m^3/s) was significantly reduced compared to the peak day inflow flood discharge (12,100 m^3/s), a reduction of 42%.

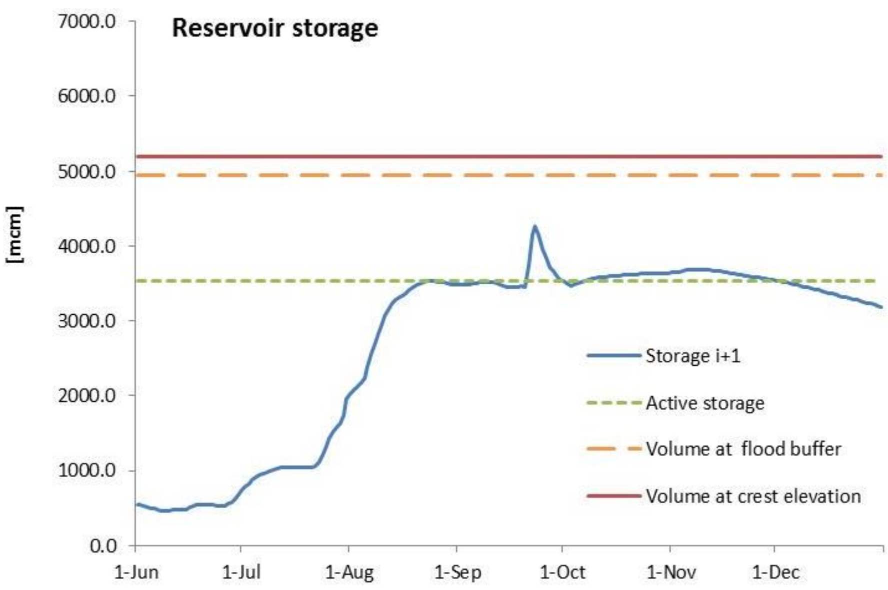

Figure 5-1: Water surface level with time, Nam Theun 2 reservoir, with simulation for inflows equivalent to year 2002 flood season runoff under scenario A. *normal operation (a satisfactory one), with well timed opening of gates, and all gates working.*

In Scenario B, human and mechanical error: a 'too-little-too-late operation', we assumed that one of the five gates could not be opened because of a mechanical or electrical problem, so that only 4 gates were available to pass the flood at the dam. Discharge of water via the turbines continued for the whole duration. Adjustments to the gates were made with a delay resulting from human error, according to the following schedule (see Table 3).

We assumed that the operator was one day late in responding to the flood, constituting delayed opening of the available gates. In this case the water level in the reservoir rose to within a fraction of a meter of the top of the saddle dam (see Figure 5-2) and was at that level for many hours.

Table 3: Procedure for opening spillway gates of Nakai Dam for example flood under scenario B. Human and mechanical error (unsatisfactory)

Date	Spillway gate opening
1st Jun-14th Aug	Spillway gates closed, release from reservoir only via turbine discharge
15th Aug	Fractional opening of one gate to allow discharge of 300 m3/s. Maintenance of reservoir level at approximately full supply elevation
20th Sept	Major rainfall event starting. One gate opened
21st Sept	Crest of major inflows. Two gates fully opened. Saddle dam comes close to breaching on account of extremely high water levels and insufficient spillway release
22nd to 27th Sept	Inflows declining. Four gates fully opened to discharge 5600 m3/s. One gate not openable because of mechanical/electrical breakdown
28th to 30th Sept	Inflows declining. Keep 2 gates open to return reservoir level to FSL
1st to 3rd Oct	Inflows declining. Keep 1 gate open to return reservoir level to FSL
28th-30th Sept	Inflows declining. Keep 1/5 gates open. Reservoir is returned to FSL
1st–8th Oct	Inflows declining. Keep a gate one half open. Allow slight bounce back to FSL
9th Oct onwards	Gates closed. Reservoir surface close to FSL for several weeks

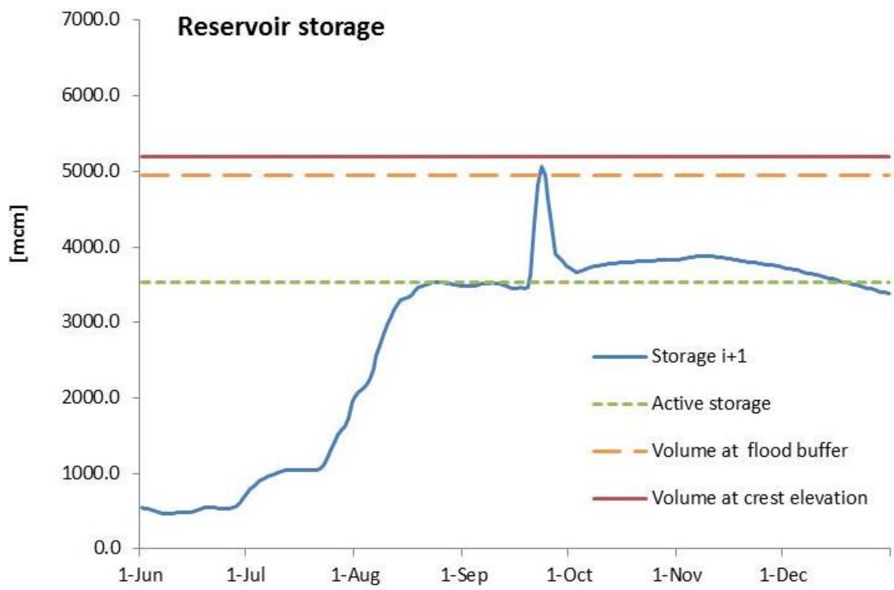

Figure 5-2: Reservoir water surface levels with time: *Nam Theun 2 reservoir, with simulation for inflows equivalent to year 2002 flood season runoff under scenario B. Human and mechanical error 'too-little-too-late' operation, with only 4 out of 5 gates opened*

This situation, which would be beyond the flood design capability of the reservoir, is associated with risk of overtopping one or both of the NT2 dams, with a potentially extremely serious dam break, and which clearly should be avoided at all costs.

Note that timing of gate opening is critical for this project, and a delay of one day at the beginning of the flood created a highly hazardous situation.

6 DISCUSSION

Operation of dams in countries with established treaties and river basin agreements has largely been in climates that have an element of snow melt contribution to flooding. As such, this provides an opportunity for flood notice that may be weeks in advance, and allows operators adequate time to prepare for possible severe flooding. In tropical climate regions, advance warning of the onset of severe flooding is problematic, as is the year to year and decade to decade variability in climate.

Experience at some dam sites in Thailand has been that modifications were needed after a few years of operation. At one Electricity Generating Authority of Thailand (EGAT) high hazard site, Srinagarind dam, a review of hydrological conditions in the Khwae river basin led to recommendations by the expert engineering team to operate flood season reservoir levels more conservatively than had been the case in the past (Champa et al 1988, SNC Lavalin 1999). At another site, Ubol Ratana Dam, a potential dam collapse was narrowly averted in 1978 after extremely high water levels in the reservoir overtopped the core of the dam (Boonpiraks et al 1988). EGAT engineers decided that the original design flood magnitude was insufficient, and in the following decade the dam crest was raised by 3.1 m to provide additional flood surcharge capacity in the reservoir, and the capacity of the spillway was increased. This high cost, additional work, was completed in 1987.

Dam operation and flood control in the NTNK basin is complicated by the climate, with periodic extremely heavy rain in the late monsoon season. Advance warning for these events is at the best a few days only, which makes dam operation more difficult than say dam operation in snow melt controlled climate regions. Extreme vigilance is needed, and there is a requirement for vital components of the dam to be in 100% working order during this period. Back up systems, such as emergency power supplies, must be totally reliable, as there is insufficient time to effect repairs during typhoon related floods. Although the amount of downstream infrastructure in the NTNK basin downstream of the TH dam is small, there is a clear need to operate the dams within a satisfactory safety range. At risk are the dams themselves, and downstream inhabitants and infrastructure. Because saddle dams that contain the NT2 reservoir prevent spillage into the Se Bang Fai river basin, there is a need for flood emergency preparedness measures in this basin, as well as in the NTNK basin.

The design of the Nakai dam at the NT2 project provides modest spillway capacity, and leaves the dam operator dependent on emergency storage in the reservoir, above the full supply level, for safe passage of extreme floods from unusual rainfall events. In the example flood discussed in the previous section, a delay of only one day, in combination with one spillway gate not functioning, produced a water level situation that was critical for dam safety. With a trend to more severe extreme weather associated with global warming, there is the likelihood that management of water levels in the NT2 reservoir will be more challenging in future decades than at present.

The Nam Gnouang dam (see Table 1) has large spillway capacity, combined with large emergency water storage in the reservoir above the full supply level. The capacity of the NG spillway is 130% greater than the spillway at NT2 Nakai dam, although the basin area is 73% of the size of the NT2 basin. This means that the chance of reservoir water levels causing overtopping at the NG dam is extremely low. The large spillway capacity however, presents future risks for downstream infrastructure, as opening the gates to their full extent would produce a flood flow of unprecedented magnitude.

A brief review of knowledge about typhoons and tropical storms in the western Pacific reveals a rich source of information. Tracks of typhoons for the last decade and a half, shown in Figure 6-1, show that a substantial number pass over the NTNK river basin after landfall on the Vietnam coast. Typhoons that are close to the basin but not over it are also important, because of the immense size of these weather conditions. Because these events are tracked as they are happening, there is a promising possibility for advance warning of likely heavy rain, albeit only a day or two ahead of the event.

The NTNK basin is in a location where there is medium-high correlation between rainfall and the Western North Pacific Monsoon (WNPM) index (Delgado et al 2012). The authors state 'enhancements in either the intensity of the circulation or in its inter-annual variance are thus likely to have consequences for flood hazard'. Note that the WNPM has become more variable since 1976 (Wang et al., 2001), implying greater extremes of rainfall and flooding. In another paper on the Mekong river basin (Delgado et al 2010), the authors found that the likelihood of Mekong River extreme floods increased during the last half of 20th century, whilst the probability of average floods decreased.

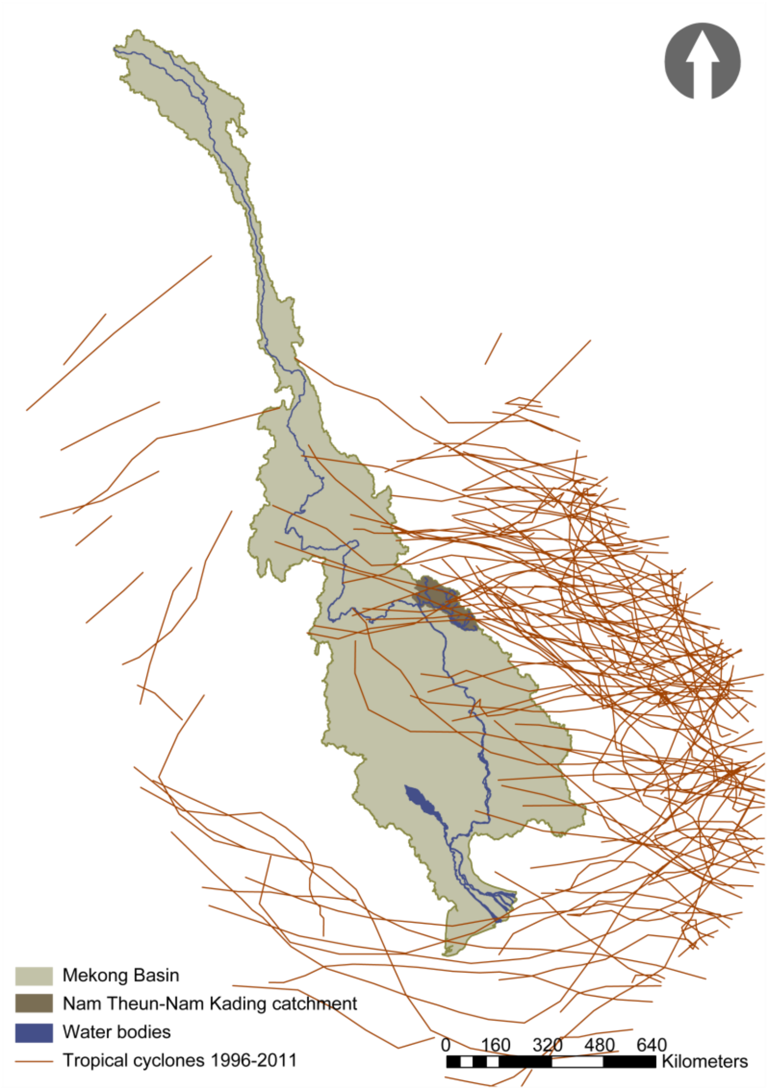

Figure 6-1: Tropical cyclone tracks 1996-2011 for Mekong River Basin and location of NTNK Basin:
Only cyclone tracks within 500km distance from the Mekong Basin are shown

Räsänen et al. (in press) used palaeoclimatological data to find that the inter-annual variation between very wet and very dry years in the Mekong have significantly increased in recent decades, to levels which have not been experienced in the last seven hundred years. The findings of both Delgado et al. (2010, 2012) and Räsänen et al. (in press) suggest that the climate variability in the Mekong has increased, together with the likelihood of large floods.

The Mekong Basin is under the influence of El Niño Southern Oscillation (ENSO) (Räsänen and Kummu, 2013). ENSO influences the Mekong regional climate by moderating monsoon intensity. During El Niño the rainfall is generally below average and the flood season shorter than average. During La Niña the rainfall is generally above average and the flood season longer than average. For example, the recent major flood years of 2000, 2001 and 2011 in the Mekong were La Niña years. Räsänen and Kummu (2013) suggest that there is a good potential for predicting ENSO impacts on the Mekong's hydrological regime.

An understanding the driving factors of the Mekong region's hydrological regime, such as WNPM, ENSO and tropical cyclones, would be highly useful for dam operators – especially if predictive tools were available. The development of these predictive tools would, however, require collaboration with national and regional meteorological agencies. Predictive tools would help indicate to dam operators in which years to expect a high alert season for tropical cyclones and accompanying severe flooding.

7 FLOODS AND RISK MANAGEMENT

The task of minimising the risk of potential downstream damage requires good governance and public awareness. One aspect is the establishment and strengthening of government-industry entities that will take responsibility for flood prediction and flood control in the basin, and in neighbouring basins affected by diversion flows.

The Department of Meteorology and Hydrology, Ministry of Agricultural and Forestry, Lao PDR, issues annual reports on flooding and flood damage, such as Phonevilay 2007, 2011. These state how warnings of heavy rainfall, floods, and flood preparedness are transmitted from central government to provincial governors, districts, village chiefs and rural inhabitants (Phonevilay 2007).

The National Disaster Management Office (NDMO), established 1999, is the main government agency to implement disaster management programs.

Existing institutions, such as the NTNK River Basin Committee Secretariat, need strengthening, and their terms of reference should include emergency preparedness related to floods. A river basin flood team needs to be established to issue forecasts concerning daily and seasonal river flow predictions. An encouraging development is the recently approved Lao Electrical Power Technical Standard, part of which requires the dam operator to have an Emergency Response plan, developed in coordination with the Ministry of Labour and Social Welfare.

With two new projects now in operation, and one downstream project (Theun Hinboun) that has been operating for several years, it is important that there is a process of co-operation and advance warning in the NTNK river basin for flood control. Ideally this process should also feed in to design considerations for possible future projects, including Nam Theun 4, and Nam Theun 1 dams.

As part of risk management, we suggest that dam operators and owners ensure that current and future procedures include the following:

- Adherence to a well-conceived rule curve for reservoir surface levels in the flood season, with periodic updating to reflect improved knowledge of the basin, and long-term shifts from climate change
- Ready access to long-term and short-term weather predictions, particularly for heavy rain expected from typhoon events.

- Responsiveness to daily and hourly developments during major floods
- Periodic comprehensive dam safety reviews, by an independent team that should include engineering experts with professional backgrounds in hydrology, geotechnology, mechanical engineering and electrical engineering.

An informal arrangement is already in place, allowing communication between the operating rooms of each power company, with NT2PC providing a day's notice to THPC before operating spillway gates. With more projects planned in the basin, the Laos PDR government will need to establish a mechanism for co-operation within the NTNK basin, so that project owner-operators know from hour to hour during major floods how other dams are being operated with regard to flood spillage.

8 CONCLUSION

The Nam Theun-Nam Kading basin is unusual in the Mekong basin, in that it sits in line with the track of major annual tropical cyclones. Proximity to the Vietnam coast together with orographic effects from the mountains combines to produce very high annual rainfall and very high variability associated with the presence or absence of typhoon rain. Existing hydroelectric plants in the basin (Nam Theun 2, Nam Gnouang and Theun Hinboun) are characterized by modest or very small storage volumes, which mean that daily rates of rise in reservoirs may be high. Without spillage, rates of rise of 3½ m/d in Nam Theun 2 reservoir are possible during extreme runoff events. This presents challenges for dam operators, for communications between operators of the cascade of dams in the basin, and for extreme reliability of spillway gate mechanisms. There is a great need for improvements to rainfall prediction accuracy over the relatively small area of the basin.

Given the background of 'close calls' in the region, with dam overtopping and potential collapse, there is a need for co-ordination and a clear command structure for routing major floods, such as 10-year events, through the Nam Theun-Nam Kading basin. This is a matter of national concern for Laos, and strengthening of emergency preparedness capability in relation to flooding is vital.

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