Many people depend profoundly on Mekong River aquatic resources.
Photo: Gregory Thomas, NHI.

A boy in a basin navigates through a floating village in Tonle Sap Great Lake, Cambodia, on September 13, 2009.
Photo: Sitha Som, Conservation International.

Tonle Sap River draining into the lake. Note the river settlements, on March 16, 2009.
Photo: Teo Wind, Malaysia.

A CLIMATE RESILIENT MEKONG PROJECT

TECHNICAL MEMORANDUM ON OPTIONS FOR SEDIMENT PASSAGE THROUGH

LOWER SE SAN 2 DAM

Submitted To: Ministry of Industry, Mines, and Energy &
Ministry of Water Resources and Meteorology
Kingdom of Cambodia

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Major Initial Funder: Project Coordinator

April 21, 2013

EXECUTIVE SUMMARY

This report presents the outcome of a preliminary study of sediment management options for the Lower Se San 2 Dam, planned by the Kingdom of Cambodia for construction downstream of the confluence of the Se San and Sre Pok Rivers. Sediment passage through the reservoir and dam is necessary because maintaining sediment flows is vital for securing the livelihoods of several million people dependent on the fisheries in the Tonle Sap, the mainstream of the Mekong River, and in the Mekong Delta. Review of the design of the Lower Se San 2 Dam revealed that it is not possible to improve sediment passage without changing the project concept. Therefore, the objective of this study was to develop an alternative project that may generate virtually the same amount of energy as the proposed project, with the added advantage that it can concurrently pass significantly greater amounts of sediment that is required to nurture downstream aquatic resources.

The Lower Se San 2 Dam is so large that it is not possible to devise strategies to pass significant amounts of sediment. Estimates indicate that the proposed Lower Se San 2 Dam will deprive the Mekong River, Mekong Delta and Tonle Sap of about 2,423 million cubic meters of sediment over the long term. By contrast this study demonstrates that it is possible to pass about seven times more sediment if an alternative project comprising four much smaller dams is built. The amount of sediment that will be prevented from passing downstream will reduce to about 358 million cubic meters if the alternative project is constructed. This significant improvement in the ability to pass sediment can be accomplished without a noticeable reduction in the amount of power that can be generated. The estimated installed capacity of the alternative project is equal to about 90% of the installed capacity of the proposed Lower Se San 2 project.

It is recommended that serious consideration be given to constructing the alternative project comprising four smaller dams that is identified in this report. Construction of the alternative project will result in the ability to generate virtually the same amount of energy as the proposed project, while significantly reducing the potential harm to the Mekong River, Mekong Delta and Tonle Sap. The alternative project will increase by seven-fold sediment flows to the downstream resources.

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1.0   INTRODUCTION

This report presents the outcome of a preliminary study of sediment management options for the Lower Se San 2 Dam, planned by the Kingdom of Cambodia for construction downstream of the confluence of the Se San and Sre Pok Rivers. Consideration of alternative designs to improve sediment passage through the proposed facility is important because maintaining sediment flows is vital to the health of the downstream fisheries in the Tonle Sap, the mainstream of the Mekong River, and in the Mekong Delta. Sediment passage is also relevant to increase the longevity of the hydropower facility, an issue of great importance to the Kingdom of Cambodia to ensure continued and effective use of the facility once the 40 year concession period is over. At the end of the concession period Cambodia intends to use the dam and its reservoir to generate hydropower for domestic consumption for as long as possible. This will require dam siting, design and operations to pass rather than trap the inflowing sediments.

The proposed Lower Se San 2 Dam is reportedly a 400 MW hydropower project, which is located downstream of the Se San River and Sre Pok River confluence (Lat 13° 34.0', Long 106° 12.3'). Figure 1 shows the project location. The full supply level of the reservoir is 75 masl with the dam length of 7,729 m. This will create a large reservoir that extends about 50 km upstream from the dam towards both Se San and Sre Pok Rivers.
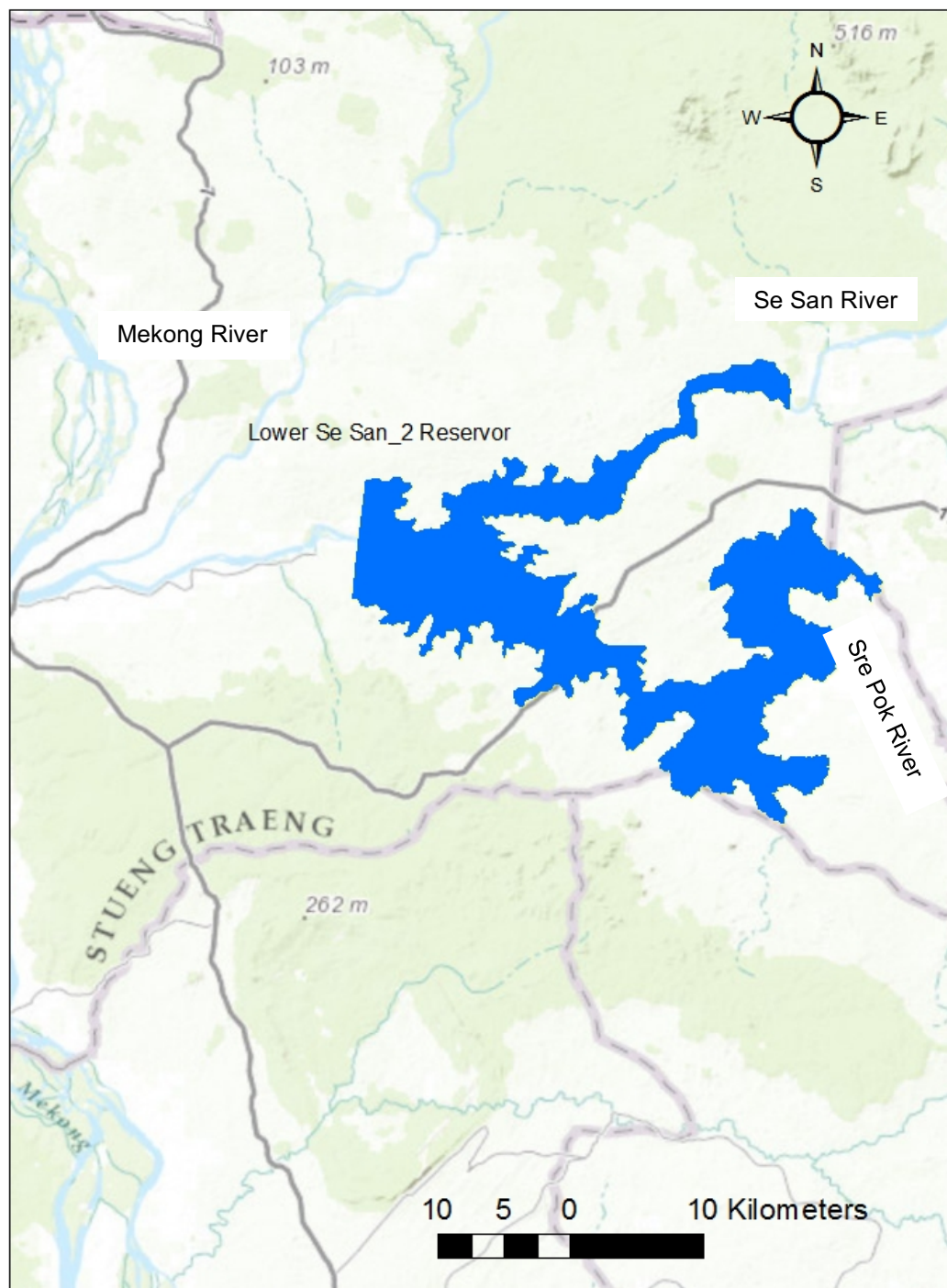
Figure 1 Proposed Dam Location of Lower Se San_2 Project

2.0   APPROACH

2.1   Introduction

The study entailed evaluating the potential to pass sediment through Lower Se San 2 Dam and its reservoir by making use of established reservoir sedimentation management techniques. This was done by first considering the potential to pass sediment through the currently proposed dam. Once it was established that the sediment passage ability of the currently proposed dam cannot be improved, an alternative project concept was developed and analyzed. These studies were executed at pre-feasibility level and will require further refinement during the feasibility and design stages of the alternative project.

2.2   Data

Flow and sediment data and the information on reservoir type and size were obtained from various sources (such as ICEM, 2009; Meynell, 2011; and http://www.3sbasin.org/iucn/). Additionally, Golder obtained topographic information from Google Earth.

2.3   Sediment Management Alternatives

At least eleven different techniques exist to manage sediment in reservoirs (see, e.g., Annandale 2011). Not all of these techniques are viable for increasing sediment passage through Lower Se San 2 Dam and the alternatives that were reviewed. After consideration of the problem, it was decided that the reservoir sedimentation management techniques with the greatest potential for passing sediment through Lower Se San 2 Dam and its alternatives might be drawdown flushing and sluicing. These techniques are described below.

2.3.1   Drawdown Flushing

2.3.1.1   Description

The objective of drawdown flushing is to erode and remove previously deposited sediment from a reservoir and discharge it downstream (Atkinson, 1996). This is accomplished by first emptying the reservoir and allowing the river flowing through the reservoir to erode and transport the previously deposited sediment. During drawdown flushing a reservoir is brought to the original river-like condition by releasing reservoir flows through bottom outlets or large radial gates if a dam is low enough. This is usually executed during a low-flow period, preferably just prior to the monsoon. By implementing drawdown flushing just prior to the monsoon allows the reservoir to be refilled with water once drawdown flushing is complete.

It is important for flushing flows to freely discharge through the low-level outlets or radial gates without damming; therefore the drawdown flushing needs to be implemented during low-flow periods. Sediment is eroded by water flowing in single or multiple channels through the previously deposited sediment in the reservoir. The success of sediment removal by flushing depends on the reservoir size, geometry (such

as width of the reservoir, the valley side slopes and longitudinal river-slope), location of the low-level outlets, the type of sediment deposited in the reservoir, and the magnitude of the flushing flows.

A distinguishing feature of drawdown flushing is that it requires emptying a reservoir and allowing the formation of river-like flow conditions over the previously deposited sediment. This requires the use of low-level or large radial gates to discharge the eroded sediment downstream freely. The creation of river-like conditions requires that drawdown flushing be implemented during low-flow periods, i.e., during the non-monsoon season. Once drawdown flushing is complete, the outlets are closed and the reservoir filled with water for continued power generation.

2.3.1.2   Assessment Criteria

White (2001) provided criteria to assess the potential for successful drawdown flushing. In general, drawdown flushing is successful in narrow, steep reservoirs where the sediment transport capacity of the water used to execute drawdown flushing is large enough to remove the amount of sediment that has deposited within a reservoir between flushing events. In order to implement drawdown flushing it is obviously also necessary to have available low-level outlets that are large enough to drain the reservoir and to freely discharge re-entrained sediment downstream.

To assist dam designers in decision-making, White (2001) devised six parameters that may be used to determine the potential success of drawdown flushing. The proposed parameters were validated by using data from 14 dams where drawdown flushing has been implemented in the past. Drawdown flushing was deemed successful at six of those dams and unsuccessful at the remaining eight. This recorded experience provides a good basis for predicting potential drawdown flushing success at other projects. The six criteria are conceptually presented in what follows. More detail may be found in White (2001).

2.3.1.2.1   Sediment Balance Ratios (SBR and SBR$_d$)

The sediment balance ratio (SBR) quantifies the ability to re-entrain and transport previously deposited sediment during drawdown flushing. The SBR is the ratio between the amount of sediment that may be removed by the water flowing through the reservoir during drawdown flushing and the amount of sediment that has deposited in the reservoir between drawdown flushing events. Conceptually, the SBR is defined as follows:

$$SBR = \frac{Sediment\ volume\ that\ may\ be\ removed\ during\ flushing}{Sediment\ volume\ deposited\ between\ flushing\ events}$$

Due to the fact that the sediment transport capacity of the water used during drawdown flushing is determined by the amount by which the water surface in the reservoir is drawn down, White (2001) also

proposed to use an additional criterion, which is the SBR if the reservoir is drawn down to the maximum extent possible. He named that parameter SBR_d.

The SBR represents the sediment balance ratio if the water level at the dam is drawn down to the elevation of the low-level outlet. Such an outlet may not be located right at the bottom of the dam, due to design constraints. The SBR_d parameter provides an indication of the ***potential*** to successfully flush the sediment from the reservoir should one be able to install a low-level gate at that level and drawdown the water surface to erode deposited sediment and release it downstream. For flushing to be successful both SBR and SBR_d must be greater than one, i.e., the potential amount of sediment that may be flushed out of a reservoir must be greater than the amount of sediment that deposited in it during the period between flushing events. SBR_d will always be greater than SBR.

1.1.1.1.1 Drawdown Ratio (DDR)
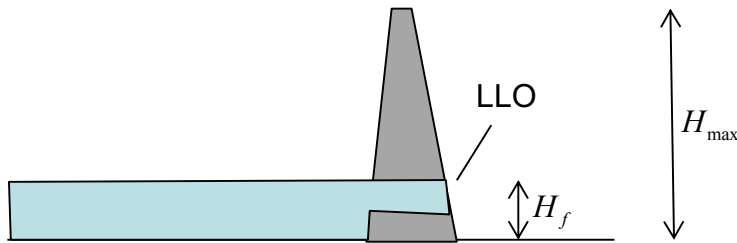
Figure 2 **Variables defining the DDR**

Another parameter devised by White (2001) is known as the drawdown ratio (DDR). This parameter quantifies how far the water surface elevation can be drawn down using a low-level outlet (LLO) or a radial gate. The parameter is defined as:

$$DDR = 1 - \frac{H_f}{H_{max}}$$

The meaning of the variables H_f and H_{max} are shown in Figure 2.

By making use of the records of fourteen projects where drawdown flushing has previously been implemented, White (2001) found that drawdown flushing may be successful if DDR > 0.7(see further on).

2.3.1.2.2 Flushing Width Ratio (FWR) and Top Width Ratio (TWR)

The two ratios known as the flushing width ratio (FWR) and the top width ratio (TWR) provide some idea of the ability to remove substantial amount of deposited sediment from a reservoir by means of drawdown flushing. Figure 3 represents an average cross section of a reservoir valley. Suppose that sediment has filled the entire valley and that an attempt to remove sediment through drawdown flushing is made. When using drawdown flushing a channel is eroded into the deposited sediment. The dimensions of that

channel are defined by W_f and W_{ftop}, i.e., the bottom width and the top width of the channel that is eroded into the deposited sediment during the flushing event. The dimensions of the original reservoir valley are defined by W_{bot} and W_{top}, i.e., the bottom and top widths of the reservoir valley.
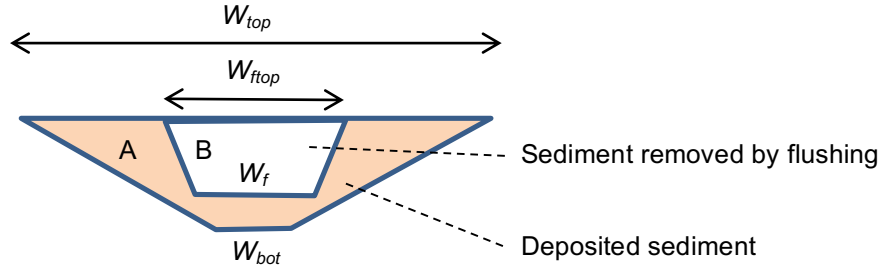
Figure 3   Cross Section of Reservoir Valley and Variables Used to Quantify FWR and TWR

The FWR is defined as:

$$FWR = \frac{W_f}{W_{bot}}$$

And the TWR is defined as:

$$TWR = \frac{W_{ftop}}{W_{top}}$$

From Figure 3 it can be seen that if drawdown flushing results in both the top and bottom widths of the eroded channel exceeding the top and bottom widths of the reservoir valley, then all the sediment would have been removed. Therefore, in the ideal case drawdown flushing would be successful if both the FWR and TWR parameters are greater than one. In cases where they are slightly less than one, it may mean that only part of the sediment may be removed. It means that some but not all of the reservoir storage space may be preserved in the long term.

2.3.1.2.3   Long-Term Capacity Ratio (LTCR)

From a practical point of view, it may not be possible to remove all deposited sediment from reservoirs by making use of drawdown flushing, as indicated in the previous section. Therefore, what one wishes to know is how much of the original reservoir volume can be preserved in the long term if drawdown flushing is regularly implemented. The long-term capacity ratio (LTCR) provides a measure of how much of the reservoir volume might be preserved in the long term when regularly implementing drawdown flushing. It is defined as the ratio between the cross sectional area of the channel eroded into the deposited sediment (the area B in Figure 3) and the total cross sectional area of the reservoir valley prior to sedimentation (the sum of area A and area B in Figure 3), that is:

A Climate Resilient Mekong

$$LTCR = \frac{Area\ B}{Area\ A\ +\ Area\ B}$$

2.3.1.2.4   Validation of Criteria

The criteria defined in the previous sections are used in the RESCON model (Palmieri et al. 2003) to assess the potential success to use drawdown flushing to remove deposited sediment from reservoirs. That model, i.e., the RESCON model, has been used to assess the dams and reservoirs investigated in this study. The criteria used in the RESCON model are shown in Table 1.

Table 1 Drawdown Flushing Criteria Used in the RESCON Model

Parameter Name	Criterion
SBR	> 1
LTCR	> 0.35
DDR	> 0.7
FWR	> 1
TWR	~ 1
SBR$_d$	> 1

The viability of these criteria to predict the potential success of implementing drawdown flushing to remove adequate amounts of deposited sediment from reservoirs were reviewed by White (2001). He used information obtained from fourteen projects to perform the assessment. Drawdown flushing was deemed successful at six of those projects, and unsuccessful at the other eight.

Figure 4 and Figure 5 compare the calculated values of SBR, FWR, LTCR and TWR with the criteria set in Table 1. The comparison of the DDR values is shown in Figure 6. It is observed that the criteria are substantially satisfied. These criteria were therefore used to assess the potential for drawdown flushing at Lower Se San 2 and the alternative designs proposed in this study.
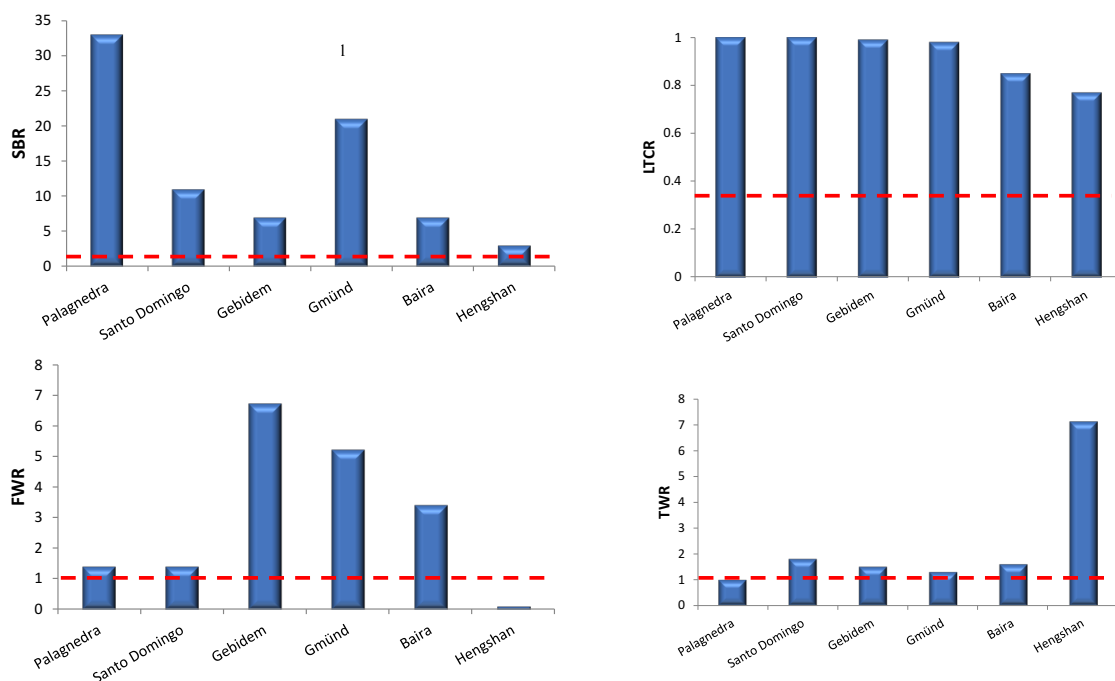
Figure 4   **Comparison of Flushing Criteria Parameter Values at Reservoirs that have been Successfully Flushed (White 2001)**
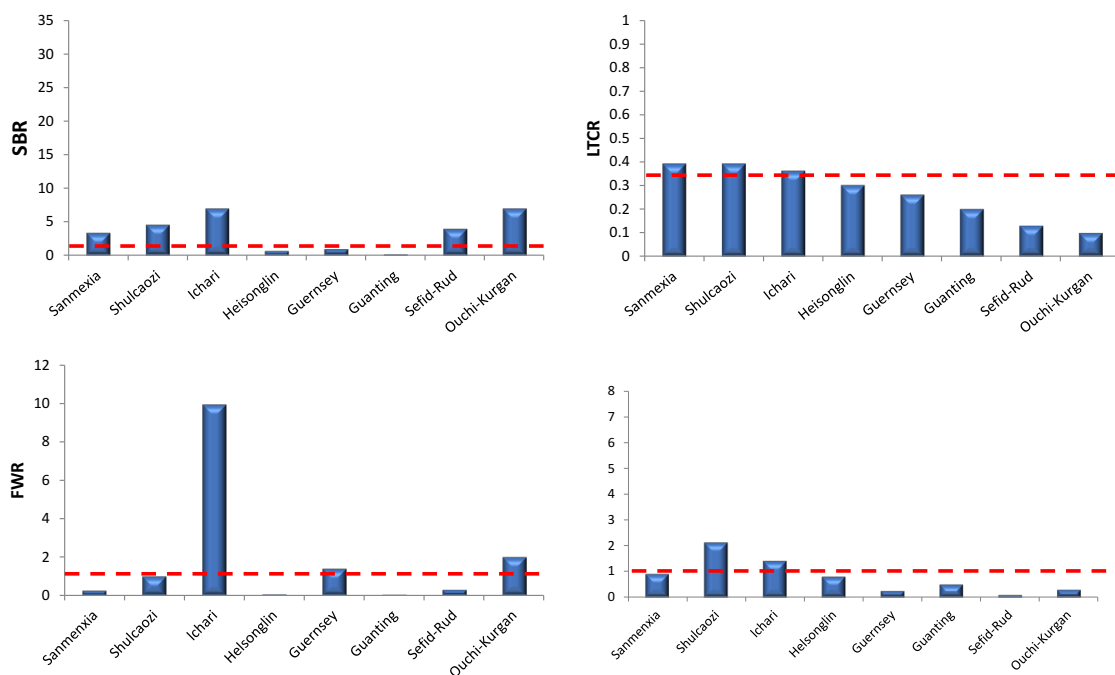

Figure 5   **Comparison of Flushing Criteria Parameter Values at Reservoirs that have not been Successfully Flushed (White 2001)**
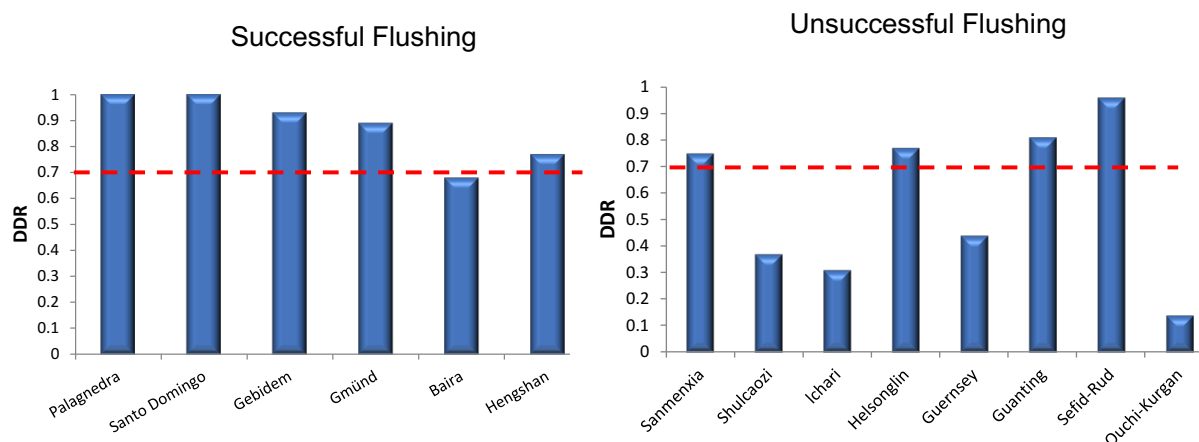
Figure 6   Comparison DDR Parameter Values and Criteria for Reservoirs that are Known to have and have not been Successfully Flushed (White, 2001)

2.3.2   Sluicing

2.3.2.1   Description

Sluicing is a sediment management technique implemented during floods, i.e., during the monsoon. The objective of sluicing is to minimize the amount of sediment that will deposit in a reservoir. This is done by creating flow conditions in a reservoir that are characterized by high sediment carrying capacity. In the ideal case, which is seldom accomplished, the sediment transport capacity in the reservoir will be equal to the sediment transport capacity of the river carrying sediment into the reservoir. Should it be possible to accomplish this goal the amount of sediment carried into a reservoir from upstream (S_1) will equal the amount of sediment discharged downstream (S_2), with no net amount of sediment depositing in the reservoir (Figure 7). Sluicing is also known as the concept of ".. releasing dirty water and retaining clean water …", often used in China.

The sediment transport capacity in the reservoir is maintained at a high level by drawing down the water surface elevation at the dam as much as possible while floodwaters flow through the reservoir. By doing so, the energy slope of the water flowing through the reservoir is increased, thereby maximizing the sediment transport capacity of those flows. The water surface elevation at the dam is drawn down by using low- and / or mid-level gates at the dam. It is obviously not possible to draw down the flows in a reservoir to the same extent required by drawdown flushing. The reason for this is that sluicing is implemented during high flows (the monsoon) when the rate of flow into the reservoir is normally larger than the free-flow discharge capability of low-level outlets.

Sluicing is best implemented in narrow reservoirs, located in relatively steep rivers where monsoon flow volumes are large relative to the reservoir volume. Successful sluicing also requires provision of enough large mid- and low-level outlets in the dam that will allow the water surface elevation at the dam to be

drawn down significantly during flood flows characteristic of the monsoon. Dams that are designed with the ability to significantly draw down the water surface elevation at the dam during the monsoon have a much greater potential to successfully transport large amounts of sediment through the reservoir without deposition- thus fulfilling the purpose of sluicing.
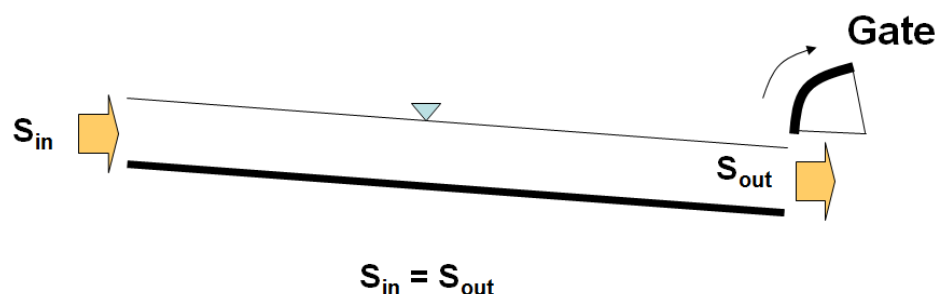
Figure 7 **Concept of Sediment Pass-through by Making Use of Sluicing**

2.3.2.2 Assessment Criteria

The engineering profession has not developed simple criteria at pre-feasibility level investigations for assessing the potential success of sluicing. The potential for implementing sluicing has therefore not been assessed during this study. It is left for more detailed assessment during the feasibility and design phases of the projects.

2.4 Drawdown Flushing and Sluicing: Essential Design Elements

Implementation of drawdown flushing and sluicing requires incorporation of low- and mid-level outlets in dams. Without the availability of such outlets it may not be possible to successfully remove or route sediment through reservoirs. It may also be necessary to install a lining in the low-level outlets to resist the effects of abrasion.

2.4.1 Outlets

Dam design elements required to facilitate successful implementation of drawdown flushing and sluicing include low- and mid-level outlets (

Figure 8). The outlets are used differently in each case.
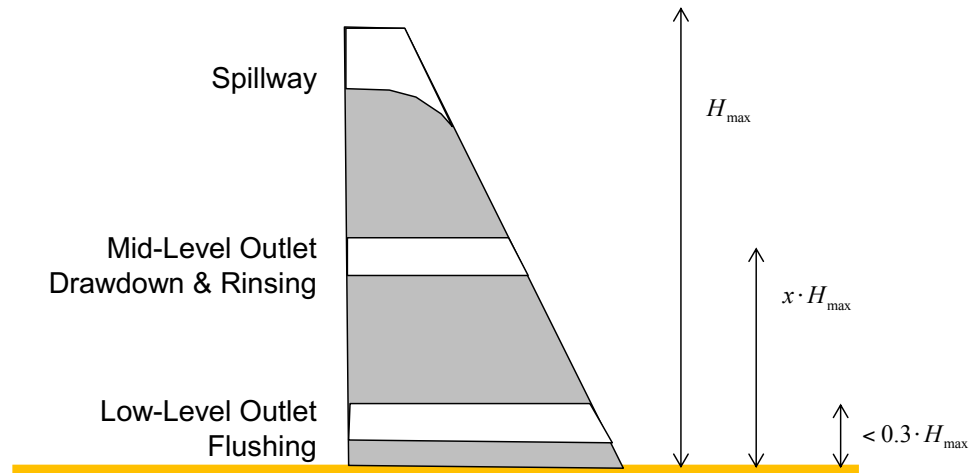
Figure 8   Essential Dam Design Elements Required to Facilitate Drawdown Flushing and Sluicing

2.4.1.1   Drawdown Flushing

To implement drawdown flushing, executed during the non-monsoon season, it is necessary to first empty the reservoir. This is accomplished by opening both the mid- and low-level outlets. Using both outlets allows rapid emptying of the reservoir. Once the reservoir is empty, the low-level outlets are used to discharge the water containing re-entrained sediment to the downstream river. After drawdown flushing has been completed, the low-level outlets are closed to refill the reservoir. When the water level reaches the mid-level outlets, they are opened to allow discharge of clean water to the downstream river. Release of this clean water is necessary to rinse the fine sediments that may have deposited along the riverbanks and on the riverbed of the downstream river reach. Rinsing the fine sediment with clean water enhances environmental conditions and appearance. After rinsing is complete, the mid-level outlets are also closed to continue filling the reservoir.

In some cases large radial gates that may replace much of the dam can be used to facilitated drawdown flushing, as proposed in this report (Figure 9). Should these gates stretch completely across the river, essentially replacing the dam structure, opening them completely essentially represents "removal of the dam" during low flows, thereby establishing natural flow conditions. The arrangement in Figure 9 may replace that in Figure 8 when dams are low enough. Using radial gates to facilitate drawdown flushing at the four dams comprising the alternative project conceived in this report is likely the preferred design approach.
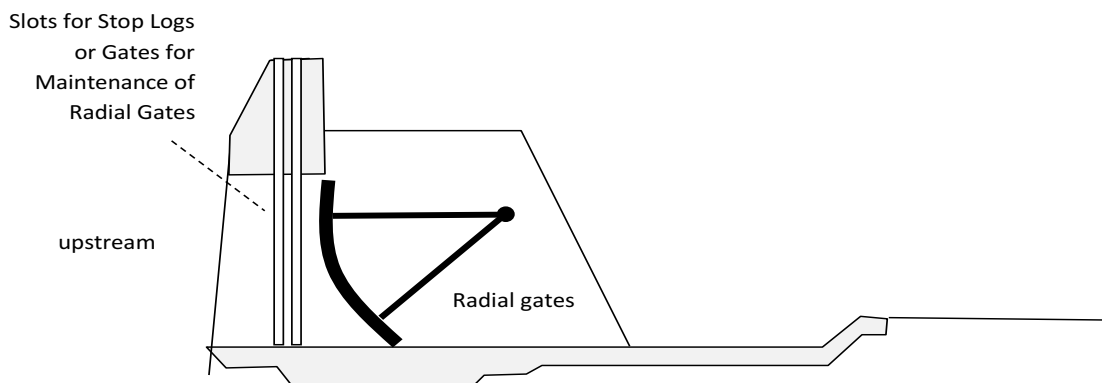
Figure 9 **Radial Gates may also effectively be used to facilitate drawdown flushing**

2.4.1.2 Sluicing

Sluicing is executed during flood (monsoon) conditions, which means that it will not be possible to empty the reservoir. The objective during sluicing, i.e., to maximize the sediment transport capacity of the water flowing through the reservoir, is accomplished by opening both mid- and low-level outlets (

Figure 88). By modulating the openings of the low- and mid-level gates it is also possible to regulate the sediment concentration in the water released downstream of the dam. Once sluicing is complete, the low-level outlets are closed and the mid-level outlets may be used to rinse fine sediments that may have deposited along the downstream river reach, if necessary. Upon completion of the rinsing process, the mid-level outlets are also closed and the reservoir refilled with water.

2.4.1.3 Lining

It may be necessary to line the low-level outlets to prevent damage by abrasion. This may be accomplished by using high-strength concrete, steel or other abrasion resistant materials like basalt tiles.

2.5 Long-Term Reduction in Sediment Load Downstream of a Dam

The reduction in sediment load to the Mekong Delta and Tonle Sap is equal to the total amount of sediment that will be deposited and remain over the long term in all upstream reservoirs constructed in the Mekong River and its tributaries. Therefore, in order to estimate the impact of dams and reservoirs on the reduction in sediment loads downstream of dams it is necessary to estimate how much sediment many deposit in a reservoir. Some of the sediment flowing into a reservoir deposits within it and some passes through. The percentage of the inflowing sediment that deposits in a reservoir is known as the reservoir's trap efficiency.

One method that may be used to estimate the trap efficiency of a reservoir is known as the Brune curve (Figure 10). The curve relates trap efficiency to the capacity-inflow ratio. The latter ratio is calculated by dividing the reservoir volume by the mean annual volume of water flowing into the reservoir. It is noted

that even relatively small reservoirs can be very effective in capturing inflowing sediment. For example, from Figure 10 it is observed that the average trap efficiency is about 85% for a reservoir with a volume equaling only about 10% of the mean annual volume of water flowing in the river in which it is constructed (i.e. a capacity-inflow ratio = 0.10).
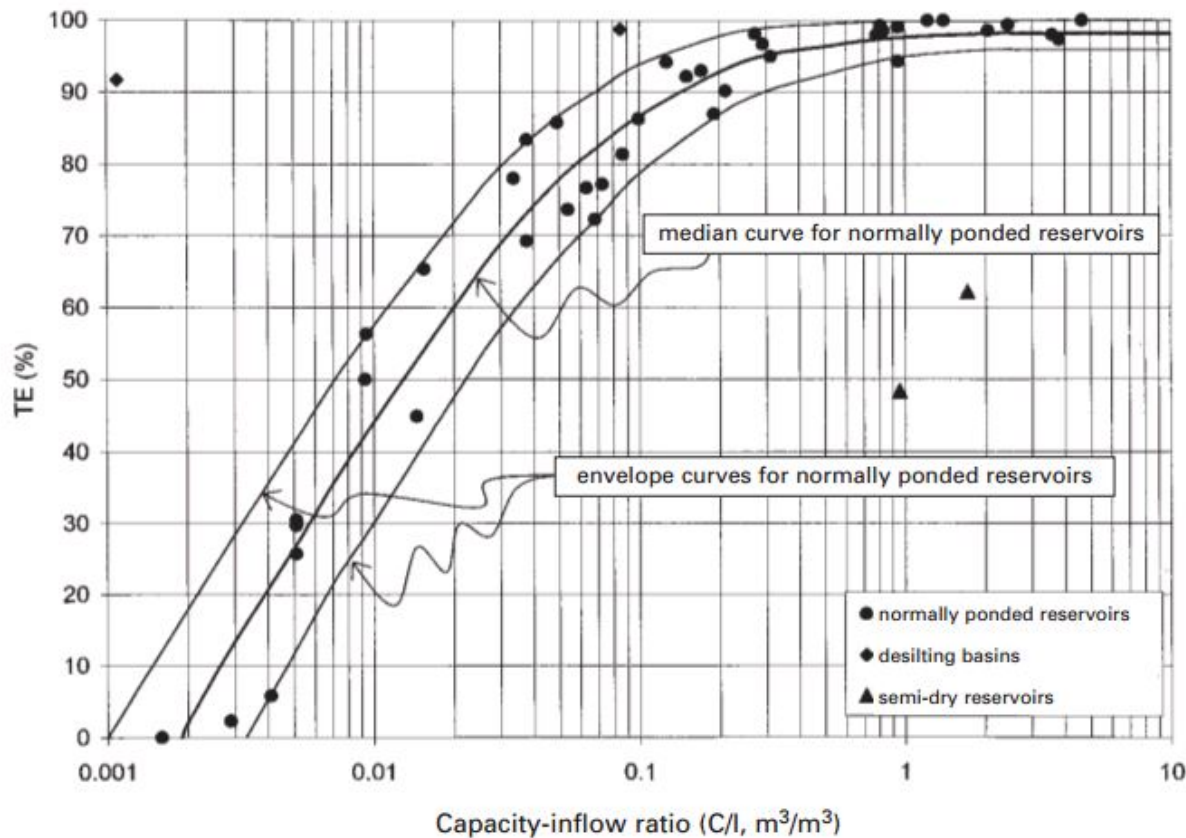
Figure 10   Brune Curve for estimating trap efficiency (Brune 1953).

As more and more sediment deposits in a reservoir, its volume will decrease. This means that its capacity-inflow ratio will decrease with time, as will the reservoir's trap efficiency. Therefore, by knowing the average annual amount of sediment that flows into a reservoir it may be possible to calculate how much sediment will accumulate over time and how long it might take for a reservoir to be substantially filled with sediment. The rate by which a reservoir is filled with sediment has operational and environmental / social implications.

2.5.1   Operational Implications

Should an operator receive a concession to build and operate a hydroelectric facility it is normal that agreement between the operator and the government specifies that the plant should be returned to the government in good order, for its continued use to generate energy once the concession period has ended. The amount of reservoir storage that is available at the time when the concession ends influences

the performance of the plant. Once a reservoir has substantially filled with sediment the amount of sediment entering turbines will increase and it may no longer be possible to use its storage. Increases in the amounts of sediment entering turbines causes abrasion, high maintenance cost and reduces the efficiency of energy generation. The inability to use storage, once the reservoir is filled with sediment, for peaking or to bridge low-flow periods, further reduces the effective use of the plant.

Figure 11 shows how the volume of a reservoir will typically diminish over time when subjected to reservoir sedimentation and ever-diminishing trap efficiency as the reservoir fills with sediment (represented by the Brune curve in Figure 10). Initially, the reservoir volume decreases relatively rapidly, but at some point in time the reservoir attains a new stable, equilibrium condition. As the amount of sediment depositing in a reservoir increases with time a condition is finally reached where the additional amounts of sediment that deposits each year becomes negligible. At that point in time the fluvial geomorphology of the reservoir has reached a new equilibrium condition and the average amount of sediment flowing into the reservoir is roughly equal to the average amount of sediment discharged downstream. This long-term equilibrium condition is reached when the capacity-inflow ratio is so small that the amount of sediment depositing in the reservoir becomes negligible. At that point in time the reservoir has lost most of its storage. The volume of sediment deposited in such a reservoir prior to reaching its new geomorphic equilibrium condition is equal to the difference between the original reservoir volume and the long-term equilibrium reservoir volume, as indicated in Figure 11.

One of the objectives in a concession agreement is to minimize the amount of sediment that will deposit in the reservoir over the long term to preserve long-term environmental and social values by maintaining the fluvial geomorphology and aquatic habitat of the Mekong River and Mekong Delta, and maintaining nutrient values associated with the sediment transported by the river and Tonle Sap. The concession agreement between an operator and the government should therefore specify the use of reservoir sedimentation management to minimize the amount of sediment that might deposit in the reservoir over the concession period. Additionally, it is also in the government's best interest to continue implementing reservoir sedimentation management approaches in the long-term to ensure sustainable generation of hydropower and maintenance of downstream natural resources, i.e. the Mekong River, Mekong Delta, and Tonle Sap.

Figure 11 illustrates the importance of the requirement for reservoir sedimentation management. It shows that the concessionaire may experience relatively minor problems due to the effects of reservoir sedimentation during the concession period because storage loss and the resulting effects of increased entry of sediment into the turbines may be relatively minor. However, at the end of the concession period, once the project is returned to the government, the remaining life of the facility may be more prone to the impacts of sediment due to the fact that the reservoir will substantially fill with sediment after its return. The long-term ability of the Government to sustainably generate power, in the absence of reservoir

sedimentation management during the concession period, is therefore compromised. Implementation of reservoir sedimentation management approaches during the concession period to minimize long-term operational impacts to the government is important.
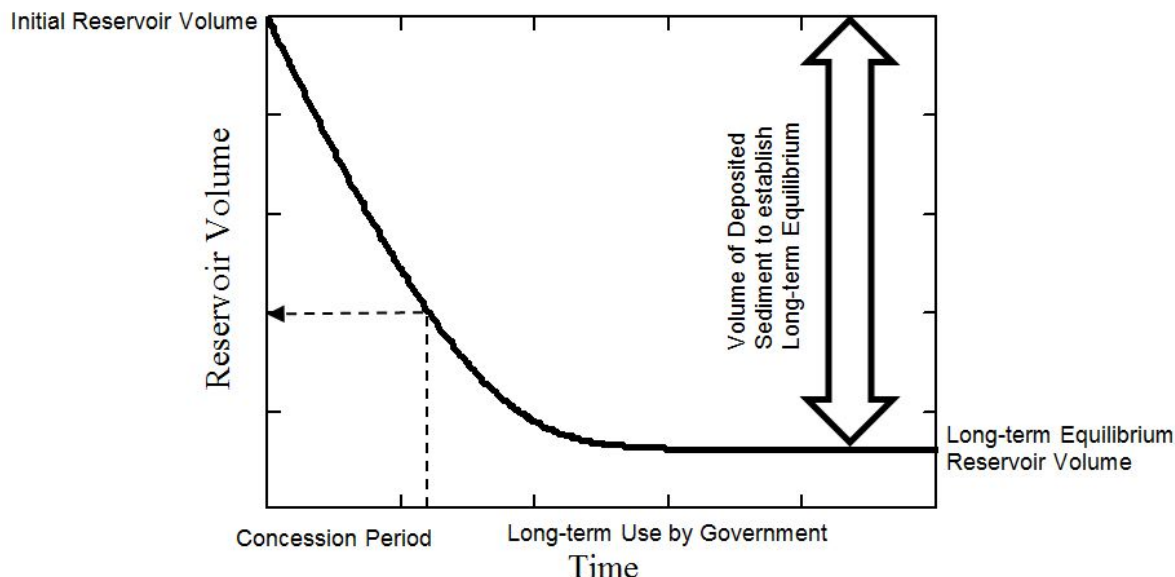
Figure 11   Typical reduction in reservoir volume due to reservoir sedimentation and diminishing trap efficiency with time.

2.5.2   *Environmental / Social Implications*

A major concern in the Lower Mekong Basin is the long-term sustainability of the Mekong River, Mekong Delta, and Tonle Sap. These natural resources form the basis of survival and well-being of tens of millions of people. Particular concerns are to maintain the fluvial geomorphology and the health of the aquatic environment of these water bodies, and their nutrient values. Sediment plays a large role in determining the success by which these goals may be accomplished.

Reducing the amount of sediment discharging to rivers downstream of dams and to the Mekong Delta will cause erosion in the long-term, thereby degrading their geomorphologic value and weakening the aquatic environment of the river and delta. Nutrients upon which fish survive are attached to sediments transported by the flowing water. Reduction in sediment transport due to reservoir sedimentation will therefore also reduce the nutrient value of the water bodies and the abundance of fish.

The social and environmental impact of reservoir sedimentation on the Mekong River, Mekong Delta, and Tonle Sap should therefore be assessed from a ***long-term (sustainability) point of view***. It is not defensible to adopt a short term view spanning, say, 50 to 60 years, which is normal practice in engineering projects. Rather the future well-being of entire nations depend on the long-term health of these natural resources. A perspective straddling hundreds of years is therefore in order. This means that

the impact of reservoir sedimentation upstream of dams built in the Mekong River and its tributaries should be viewed from a long-term outlook. The reduction in the amount of sediment discharging into the Mekong River downstream of dams is therefore quantified as the amount of sediment that will deposit in these reservoirs over the long term, i.e. until the geomorphology of these reservoirs has reached a new state of equilibrium. This is illustrated in Figure 11 as the difference between the original reservoir volume and the long-term, equilibrium reservoir volume.
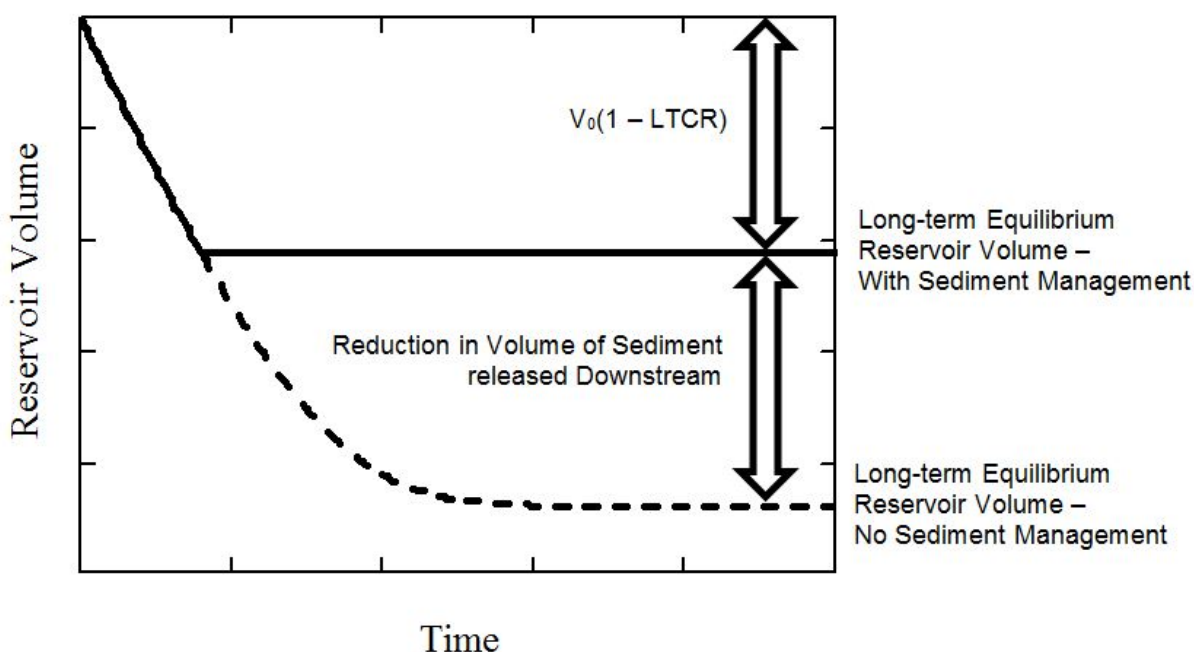
Figure 12 **Long-term effect of Reservoir Sedimentation Management on the Sediment Discharge Downstream of Dams**

2.5.3 Minimizing Long-Term Impact

The long-term impact on the Mekong River, Mekong Delta, and Tonle Sap resulting from reservoir sedimentation can be reduced by implementing reservoir sedimentation management technology. The objective with implementing the technology is to minimize the amount of sediment that will deposit in these facilities over the long-term. This is accomplished by establishing a new long-term equilibrium condition through the implementation of reservoir sedimentation management. The new long-term equilibrium is characterized by deposition of lesser amount of sediment than what would deposit without implementation of reservoir sedimentation management approaches.

The long-term benefit of reservoir sedimentation management to the Mekong River, Mekong Delta, and Tonle Sap may be explained by making use of the Long-Term Capacity Ratio (LTCR) concept defined in section 2.3.1.2.3. This concept quantifies the percentage of the original reservoir volume that might be preserved in the long term if a particular reservoir sedimentation management technique is implemented.

(In the case of section 2.3.1.2.3 it specifically refers to drawdown flushing, but similar concepts may be developed for other reservoir sedimentation management approaches).

The LTCR uniquely defines the reservoir volume that may be preserved in the long-term should reservoir sedimentation management be implemented. The amount of sediment V_{dep} that will have deposited in such a reservoir by the time the new equilibrium condition has been reached (due to implementation of reservoir sedimentation management approaches) is calculated as shown below. Effective implementation of the reservoir sedimentation management approach will result in this amount of deposited sediment not being exceeded over the long-term:

$$V_{dep} = V_0 \cdot (1 - LTCR)$$

Where V_0 = original reservoir volume.

From Figure 12 it is determined that the reduction in the amount of sediment that may be released downstream of dams over the long-term is the difference between the volumes of sediment that will deposit in a reservoir, respectively, with and without implementation of reservoir sedimentation management techniques. The aim is to develop and implement reservoir sedimentation management techniques that will maintain reservoir volumes that are as large as possible, in perpetuity. Maintaining high reservoir volumes in the long term suggests that the amount of sediment discharged downstream of dams will be maximized in the long-term. This means that methods resulting in high LTCR values are preferred. Such methods have greater potential to maintain long-term reservoir storage and minimize the amount of sediment depositing within reservoirs over the long term. The long-term objective at dams and reservoirs constructed in the Mekong River and its tributaries should therefore aim at implementing reservoir sedimentation management techniques that will result in new long-term geomorphic equilibrium in reservoirs associated with lesser amount of deposited sediment, i.e. associated with LTCR values that are as high as is practically possible for a particular dam alternative.

3.0   LOWER SE SAN_2 DAM

The Lower Se San_2 Dam has not been constructed. In an effort to maximize sediment management at the site, alternative dam sites were investigated. The alternative dam locations will allow for pro-active sediment management. The proposed dam is located downstream of a confluence between the Se San and Sre Pok Rivers (Figure 1). Therefore, sedimentation may potentially impact both tributaries, should this dam be built. Additionally, the proposed dam site is in a relatively wide valley, which impedes the potential for drawdown flushing success.

3.1.1   Sediment Management Assessment

Sources for the sediment data for Se San_2 are inconsistent. The data sources are http://www.3sbasin.org/iucn/) and the Natural Heritage Institute (NHI) Database. This assessment uses the data from the NHI database because it is consistent with the sediment yield estimates for Buon Kuop and other projects along the Sre Pok River in Vietnam. A specific sediment yield of 290 $t/km^2/year$ from the Se San watershed basin is used in this study. In Figure 13 (extracted from Google Earth), a large number of sand bars are visible in the Se San River, which indicates that the Se San River has a large sediment load.

Figure 13   **Sediment Deposition along Se San River Upstream of Proposed Dam**

A preliminary assessment of reservoir sediment management was conducted for the proposed Se San 2 Dam using a RESCON model and the following input (http://www.3sbasin.org/iucn/ and NHI Database):

Table 2 Reservoir Information of Lower Se San_2

Item	Units	Value
Reservoir capacity	mill m^3	2,483
Bottom width of the dam	m	2000.0[a]
Top level of the reservoir	masl	75.0
Minimum bed level	masl	30.0
Available head	m	45.0
Reservoir length	m	50,000
Mean inflow	m^3/s	1,304
Mean <u>natural</u> annual sediment inflow	tons/year	14,268,000

3.1.2   Results

The RESCON results for the flushing analysis are shown in Table 3.

Table 3 Se San_2: Flushing Feasibility

Flushing flow	LTCR		SBR	
	Result	Criterion	Result	Criterion
Average flow (1,304 m^3/s)	0.11		0.71	
1.5 times average flow	0.14	>0.35	1.20	>1.0
2 times average flow	0.16		1.75	

The results indicate that drawdown flushing is technically infeasible. This is because of the long and wide valley that the proposed reservoir covers. The long term capacity ratio (LTCR) is 0.11, which is less than the recommended minimum threshold (0.35) when using the average annual discharge as flushing flow (Table 3). With the given size of the reservoir, it is likely that the majority of the sediment will be trapped upstream. In the absence of sediment management, it is estimated that about 98% of the reservoir volume will be filled with sediment, i.e. 2,423 million cubic meters of sediment will remain in the reservoir and not be released downstream over the long term (based on explanation in section 2.5.1).

3.2   Alternative Dam Locations

 Based on the fact that sediment management in the proposed Lower Se San 2 Dam is not practically feasible, an attempt was made to devise a scheme that can pass more sediment while still having the ability to generate a significant amount of power. Four smaller dams in the Sre Pok and Se San Rivers, upstream of the Lower Se San 2 Dam location, have been identified as replacement for the Lower Se San 2 Dam. It is noted that the suggestion is that all four dams be built to replace the Lower Se San 2 Dam. The benefit is that these dams will have the ability over the long term to pass about 7 times more

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[a] Top width of the dam is 7,729 m

sediment than what the proposed Lower Se San 2 Dam may release, while the combined installed capacity of the four dams is 361MW (which is equal to about 90% of the installed capacity of the proposed project). It means that the potential to preserve the environmental and social values of downstream natural features will greatly improve. More sediment will be available to preserve the fluvial geomorphology and aquatic health of downstream features if the four alternative schemes are built instead of the proposed Lower Se San 2 Dam.

The locations of the four potential dams sites that were identified are shown on Figure 14 and principal features are shown in Table 4. It is noted that the Lower Se San_2 II and the Lower Sre Pok Reservoirs are contained entirely within the footprint of the proposed Lower Se San 2 Reservoir. This means that the area required to establish relocation requirements is significantly reduced.

Flow and sediment loads for these two locations were estimated using a percentage of the total Se San_2 catchment. It is assumed that 37% of the Lower Se San 2 flow and sediment originate from the Se San River and 63% from the Sre Pok River. Energy is calculated assuming that power plant is run in full design flow for 50% of the time.

Table 4 Hydropower Project Alternatives

Site	Max Water Level (masl)	Approx. Head (m)	Approx. Reservoir Length (km)	Design flow, (m^3/s)	Power (MW)	Energy (GWh)	Location
Lower Se San_2 II	70.0	14.0	16.0	784.0	86	377	13°34'N, 106°17'
Lower Sre Pok	70.0	14.0	20.7	1,335	147	642	13°31'N, 106°18'
Se San_US1	100.0	10.0	20.1	731.0	57	251	14°01'N, 106°55'
Se San_US2	125.0	16.0	14.6	569.0	71	313	13°54'N, 107°19'
TOTAL					361	1583	

3.2.1   Sediment Management Assessment

The RESCON model was used to evaluate the sediment management options for all four projects based on the information in Tables 5 to 8.

Figure 14 **Alternate Sites for four Dams on the Se San and Sre Pok Rivers to replace the Lower Se San 2 Dam**

Table 5 Reservoir Information of Lower Se San_2 II

Item	Units	Value
Reservoir capacity	mill m^3	136.9
Bottom width of the dam	m	400.0
Top level of the reservoir	masl	70.0
Minimum bed level	masl	56.0
Available head	m	14.0
Reservoir length	m	16,000
Mean inflow	m^3/s	482.0
Mean natural annual sediment inflow	tons/year	5,279,160
Mean annual sediment load with upstream dams in place	tons/year	1,934,000

Table 6 Reservoir Information of Lower Sre Pok

Item	Units	Value
Reservoir capacity	mill m^3	258.6
Bottom width of the dam	m	400
Top level of the reservoir	masl	70.0
Minimum bed level	masl	56.0
Available head	m	14.0
Reservoir length	m	20,700
Mean inflow	m^3/s	822.0
Mean natural annual sediment inflow	tons/year	8,988,840
Mean annual sediment load with upstream dams in place	tons/year	8,988,840

Table 7 Reservoir Information of Se San_US1

Item	Units	Value
Reservoir capacity	mill m^3	231.5
Bottom width of the dam	m	830.0
Top level of the reservoir	masl	100.0
Minimum bed level	masl	90.0
Available head	m	10.0
Reservoir length	m	20,100
Mean inflow	m^3/s	434.0
Mean natural annual sediment inflow	tons/year	4,751,244
Mean annual sediment load with upstream dams in place	tons/year	3,125,263

Table 8 Reservoir Information of Se San_US2

Item	Units	Value
Reservoir capacity	mill m^3	116.5
Bottom width of the dam	m	530.0
Top level of the reservoir	masl	125.0
Minimum bed level	masl	109.0
Available head	m	16.0
Reservoir length	m	14,600
Mean inflow	m^3/s	338.0
Mean natural annual sediment inflow	tons/year	3,695,412
Mean annual sediment load with upstream dams in place	tons/year	3,695,412

3.2.2 Results

All reservoirs are narrower and shorter than the proposed project, resulting in drawdown flushing being a feasible sediment management option. In all cases, the LTCR values are greater than 0.35. The SBR values indicate that the average flow can be used for drawdown flushing in all cases, except for Se San_US1. In the case of the latter dam it is necessary to increase the drawdown flushing discharge to 1.5 times the mean annual flow, which should be an achievable goal.

Table 9 Flushing Feasibility of Se San_2 and its Alternatives

Reservoir	LTCR		SBR	
	Result	Criterion	Result	Criterion
Lower Se San_2 II	0.54		3.21	
Lower Sre Pok	0.70		0.95	
Se San_US1 (434 m^3/s)	0.29	>0.35	0.64	>1.0
Se San_US1 (651m^3/s)	0.36		1.08	
Se San_US2 (338 m^3/s)	0.41		1.24	

3.3   Summary

The main features of the Lower Se San 2 Dam and its alternative are presented in Table 10, indicating that sediment flushing is expected to be viable for the alternative project (consisting of four dams) and not for the currently proposed project (based on the estimated LTCR and SBR values). Construction of all four dams comprising the alternative project is expected to result in a combined power rating approaching that of the proposed project, while concurrently allowing a significantly greater portion of sediment to be passed downstream.

Table 10 Main Features of Lower Se San_2 and Alternative Project

Dam	Lower Se San_2	Lower Se San_2 II	Lower Sre Pok	Se San US1	Se San US2
Catchment area, km^2	49,200	18,204	30,996	16,384	12,743
Mean annual flow, m^3/s	1,304	482.0	822.0	434.0	338.0
Dam height, m	45.0	19.0	19.0	15.0	21.0
Dam length, m	7,729.0	1,200.0	1,200.0	2,000.0	1,000.0
Full supply level, masl	75.0	70.0	70.0	100.0	125.0
Minimum operating level, masl	74.0	69.0	69.0	99.0	124.0
Tailwater level, masl	30.0	56.0	56.0	90.0	109.0
Vol. of reservoir, mill m^3	2,483.5	136.9	258.6	231.5	16.5
Reservoir length, m	50,000	16,000	20,700	20,100	14,600
Bottom width of reservoir, m	2000.0	400.0	400.0	830.0	530.0
Design head, m	26.2	14.0	14.0	10.0	16.0
Design flow (m^3/s)	2,119.0	784.0	1,335.0	731.0	569.0
Installed capacity, MW	400	86.0	147.0	57.0	71.0
Energy production, GWh	1,759	377.0	642.0	251.0	313.0
Sediment inflow, tons/yr (natural)	14,268,000	5,279,160	8,988,840	4,751,244	3,695,412
Trap efficiency (%)	85%	40%	42%	55%	44%
Net sediment inflow tons/yr (dams in place)	14,268,000	1,934,000	8,988,840	3,125,263	3,695,412
Flushing discharge (m^3/s)	1,300.0	482.0	822.0	651.0	338.0
Flushing duration (days)	10	10	10	10	10
LTCR (criterion > 0.35)	0.11	0.54	0.70	0.36[1]	0.41
SBR (criterion > 1.0)	0.71	3.21	0.95	1.08[1]	1.24
Deposited sed. mill m^3 (long term)	2,423[2]	63	78	148	69
Total (mill m^3 deposited sed.)- Long Term	2,423	358[3]			
Ratio	7	1			

[1] Flushing flow is 1.5 times the average annual flow;

[2] No flushing, reservoir will eventually fill with sediment;

[3] Sum of deposited sediment in four reservoirs of proposed alternative, assuming implementation of drawdown flushing.

3.4 Discussion

The main features of the proposed Lower Se San 2 Dam and its alternative are shown in Table 10, which illustrates that joint construction of the four alternative dams (the alternative project) in the place of the proposed project will provide almost the same amount of power while having the additional benefit of passing about seven times more sediment to the Mekong River. More sediment can be passed because each of the four smaller dams characterizing the alternative project allows implementation of drawdown

flushing. This is not possible at the proposed Lower Se San 2 Dam. In fact, the reservoir of the proposed Lower Se San 2 Dam is so large that it will not be practically feasible to implement any reservoir sedimentation management techniques for passing sediment.

In addition to having greater potential to pass sediment, construction of the alternative project provides opportunity to enhance fish passage. The reason for this is that each of the four dams in the alternative project is much smaller than the proposed Lower Se San 2 Dam. Implementation of fish passage facilities at the smaller dams may have a greater chance at success than implementation of such facilities at the proposed Lower Se San 2 Dam.

Based on the explanation provided in section 2.5 the anticipated accumulation of sediment in the proposed Lower Se San 2 Dam is shown in Figure 15, which relates the anticipated change in reservoir volume due to sedimentation to the number of years after project commissioning. The figure indicates that it is expected that the reservoir will almost completely fill with sediment over a period of about 300 years. The impact on the Mekong River, Mekong Delta and Tonle Sap due to this removal of sediment will therefore take place over an extended period of time. Removing without relent a total volume of 2,423 million cubic meters of sediment from the Mekong River over such an extended period of time is expected to have significant impacts on the fluvial geomorphology of the river, delta and lake system, thereby severely degrading the quality of the aquatic environment.
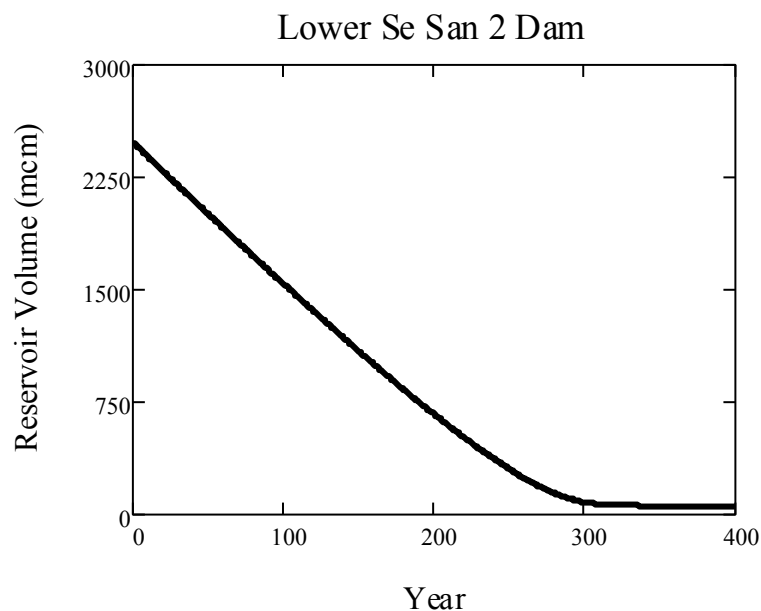

Figure 15 Predicted change in reservoir volume of the proposed Lower Se San 2 Dam due to reservoir sedimentation

This contrasts the anticipated sedimentation of the four reservoirs comprising the alternative project. The fact that drawdown flushing can be successfully implemented at each of the four dams comprising the alternative project means that much greater amounts of sediment will be passed through to the Mekong River when annual drawdown flushing is executed at the four facilities. Successful drawdown flushing at the four facilities will also result in a much smaller amount of sediment being removed from the Mekong River over the long-term. This means that significantly more sediment will be released downstream from the alternative project over both the short and long term. The estimated amount of sediment that will be removed due to permanent deposition of sediment in these facilities is only 358 million cubic meters, compared to 2,423 million cubic meters associated with the proposed Lower Se San 2 Dam. In spite of the fact that geomorphic degradation will occur if the alternative project is constructed, it is conceivable that its impact will be significantly reduced due to the lesser amounts of sediment being removed from the Mekong River in both the short and long term.

This observation raises an important point, i.e. distinction between the short and long term effects of reservoir sedimentation. The operator of the plant has a short-term view determined by the concession period. The government has a long-term view, which is predominantly dictated by its responsibility to ensure the long-term welfare of those dependent on the sustainability of the resources provided by the Mekong River, Mekong Delta and Tonle Sap. The government also has an interest to ensure that the facility is in good condition when it is returned to the government at the end of the concession period and that the original design is such that it will allow continued operation to effectively and efficiently generate power while concurrently preserving the integrity of downstream natural resources.

From an operational point of view the concessionaire's short-term view justifiably focuses on maximizing power generation over the concession period, while simultaneously aiming to minimize cost. It means that the concessionaire may view sediment management as an unnecessary expense because the sediment would likely not significantly impact its operations during the concession period, the duration of which is significantly less than the 300 years it will take for the reservoir to fill with sediment. Although this may be a defensible position from the concessionaire's point of view it does not address the long-term impact that the facility will have on the Mekong River, Mekong Delta and the Tonle Sap. The concessionaire's approach to sediment management does therefore not address the entire problem.

From a long-term sustainability point of view the government has at least two main responsibilities, i.e. to preserve the long-term livelihoods of people who are dependent on the Mekong River, Mekong Delta and Tonle Sap and to ensure that the hydropower generating facility is in good operating condition once it is returned to the government at the end of the concession period; and that it will remain so for an indefinite period of time. Responding positively to these concerns requires consideration of how much sediment might be removed from the downstream natural resources over the long term, and how long-term

sedimentation would impact power generation. Due to the fact that the amount of sediment that will be removed from the Mekong River in the long-term is significant it is in the government's best interest to insist on dam and reservoir designs allowing maximum passage of sediment. Modifying existing designs that do not have such features is very difficult. It is therefore necessary to devise designs that facilitate sediment passage right from the start. Acknowledgment of the importance of having available dam and reservoir designs that are able to effectively pass sediment in both the short and long term is of critical importance.

The government allows the concessionaire to use the natural resource provided by the Mekong River to construct a hydroelectric power generating facility and generate electric power for an agreed period of time. In setting the conditions for such an agreement the government is expected to honor the long-term point of view for the good of those dependent on the natural resources. With the knowledge that development is an inevitable need to ensure the welfare of growing populations, it is also accepted that degradation of natural resources is an unavoidable consequence of development. However, the fact that development impacts the environment and society does not mean that it should not occur. The objective should be to maximize the benefit of development while concurrently making every reasonable attempt to minimize impacts, both short- and long-term. This means that conditions in the concession agreement should fully account for minimizing the effects of these impacts. Through setting the right conditions the government sets the tone by defining how the facility should be designed, constructed and operated.

Setting standards to ensure the right design of the hydropower generating facility is enormously important. The reason for this is that the continued health of the Mekong River, Mekong Delta and Tonle Sap is dependent on the ability to manage reservoir sedimentation and pass as much sediment as possible through the hydropower facilities. This means that the dam design must be prepared in a way that provides both the concessionaire and the government the opportunity to manage sediment throughout the entire existence of the facility, i.e. in both the short- and long-term.

The design of the dam and reservoir determines whether sediment can be passed or not. Allowing an incorrect design to be constructed, i.e. a dam and reservoir design that does not have the ability to pass sediment, pre-determines the fate of the downstream natural resources. A design that is not focused on passing sediment limits long-term management opportunities, without much or any flexibility to change conditions in the future. Insisting on conceiving a correct design for a dam and reservoir, which has the ability to pass as much sediment as possible, is likely one of the most important features of any concession agreement for ensuring the short- and long-term health of the Mekong River, Mekong Delta and Tonle Sap.

3.5   Recommendation

Based on the findings presented in this report it is recommended that construction of the alternative project comprising four small dams instead of the proposed Lower Se San 2 Dam be considered. The
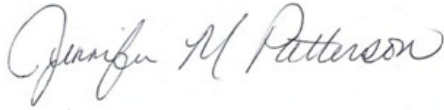
preliminary assessment indicates that sediment passage through the use of drawdown flushing is likely feasible at each of the four alternative dams. Preparing dam designs facilitating drawdown flushing is of extreme importance to maintain the long-term health of the Mekong River, Mekong Delta and the Tonle Sap.

This recommendation emphasizes the importance of preparing dam and reservoir designs that can be used to implement drawdown flushing. The alternative project comprising the four proposed dams provides such an opportunity. The estimate that about seven times more sediment can be passed downstream while still having the ability to generate about 90% of the originally proposed energy justifies serious consideration of this recommendation.

4.0   CLOSING

Golder is pleased to have the opportunity to present this report to Natural Heritage Institute. If you have any questions, please feel free to contact Jennifer Patterson or George Annandale at (303) 980-0540.

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