Mekong River Commission

Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin

Final Version

31 August, 2009

The design guidance recommended in this document is preliminary and advisory in nature. The intention is to provide developers of proposed dams on the Lower Mekong mainstream with an overview of the issues that the MRC will be considering during the process of prior consultation under the 1995 Mekong Agreement. Responsibility for ensuring compliance with national standards and provisions of the 1995 Mekong Agreement remains with the project developers. MRC may commission an international expert group to assist in the interpretation of such requirements.

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1. Purpose of the Guidance

1. At least eleven large hydropower schemes have been proposed on the mainstream reaches of the Lower Mekong Basin in Cambodia, Lao PDR and Thailand. Whereas implementation of any one, or all of the proposed schemes brings potential opportunities for economic development of the region, mainly through enhanced electricity supply and improved conditions for inland navigation, the projects will inevitably be accompanied by major impacts and other development risks in the four MRC Member Countries.

2. The impacts and risks are particularly with respect to:

- Effects on the fisheries resources of the Mekong, the world largest inland fishery, especially the barrier effect that dams could have for migratory species, fish biodiversity and the subsequent consequences for people's livelihoods;
- Effects on sediment and river morphology, with associated risks to the economic life of the mainstream impoundment of water and safe operation, and effects on long-term river bed stability, river bank erosion and channel changes in the downstream reaches;
- Potential water quality changes, especially with regard to water pollution and effects on aquatic ecosystem functions and services, as well as wetland systems, both in the mainstream channel above the dams and localized effects downstream.

3. There is also the potential for longer-term sediment and nutrient flow changes in the downstream Mekong system in relation to cumulative effects of dams in a cascade. These changes can add pressure to factors already affecting ecosystem functions and productivity in the Tonle Sap; as well as the long-term stability of the Mekong delta, including the influences of the large storage dams on the upper reaches of the Lancang-Mekong system in China and tributary dams in the lower basin.

4. Within MRC's areas of cooperation mentioned under article 1 of the 1995 Mekong Agreement and the organisation's remit to formulate a basin development plan under article 2, MRC needs to "formulate a consistent approach to evaluate the design, operation, impact and mitigation measures for any proposed mainstream dam in a basin-wide, sustainable development context". Further to this, article 3 on the protection of the environment, article 7 on prevention and cessation of harmful effects and article 9 on freedom of navigation, are relevant. The Joint Committee will also need to refer to design considerations in implementing the Procedures for Notification, Prior Consultation and Agreement (PNPCA) under Article 5 of the 1995 Mekong Agreement.[1]

5. According to the 1995 Mekong Agreement, before Member Countries may initiate any large scale infrastructure development on the Mekong, they must notify and consult with other riparian states in the basin. [2]

[1] For information on the Procedures for Notification, Prior Consultation and Agreement (PNPCA) please see the MRC Website (http://www.mrcmekong.org/) and http://www.mrcmekong.org/ish/support-PNPCA.htm
[2] Any mainstream development in the Lower Mekong, such as the proposed mainstream hydropower dams are subject to rigorous prior consultation that aims at arriving at an agreement by the Joint Committee of the MRC.

6. In addition to analysis generated by MRC Programme activities, a number of specific studies have been undertaken to inform future steps to evaluate the mainstream dam proposals in a basin-wide context. Among these, the MRC has recently undertaken an analysis of the effects of the upstream dam developments in China with respect to the reduction in wet season flows; and increases in dry season flows in the lower mainstream as an input to the Basin Development Plan (BDP). Additional analysis is being assembled in the MRC Strategic Environment Assessment (SEA) of mainstream dams and the BDP on related changes in flow regime, sediment flows and water quality due to dams in China.

7. Developers of proposed dams in the Lower Mekong mainstream will need to take these changes into consideration in their project preparation studies.

8. The MRC's Strategic Environment Assessment (SEA) will also enhance the baseline information for government review of project-specific Environment Impact Assessments (EIAs) prepared by developers, and inform how the MRC can best enhance its support to Member Countries when they begin the PNPCA process for any of these projects. The report on Mekong mainstream run-of-river hydropower, commissioned by the Mekong Secretariat in 1994 recommended that further studies, in particular on wetlands, fisheries and public health aspects should be undertaken in order to address project risks and uncertainties. The recent optimization study commissioned by the Lao Department of Electricity, Ministry of Energy and Mines on the upper five proposed mainstream dam sites in Lao PDR is also highly important.

9. This document provides preliminary design guidance in the form of performance targets, design and operating principles for mitigation measures, as well as compliance monitoring and adaptive management. Two broader aims are:

i. To ensure that developers have timely guidance in order to adopt a consistent approach to the design of individual dams, as well as the proposed mitigation and management measures. This is important, particularly where developments have significant trans-boundary impacts for people or the environment downstream.

ii. To ensure that the approach of offering performance targets allows developers the flexibility to identify and propose the best solutions.

10. The guidance is founded on a set of basic Integrated Water Resource Management (IWRM) principles, international best practice and the relevant primary legislation of Member States, namely:

- Avoidance over mitigation: Emphasis on the avoidance of impacts is preferable to the mitigation of impacts - or compensation for unmitigated impacts; taking care to avoid permanent loss of environmental assets, in particular permanent biodiversity loss.
- Water as an economic good: Responsibility for mitigation measures and economic compensation for unmitigated impacts is born by the project and users of services it

The National Mekong Committees are the submitting parties. The PNPCA is triggered when the preparation of a mainstream dam advances to the stage where the Member Country makes as submission to the MRC. The procedure will be applied to each mainstream project.

provides, consistent with national policies and interpretation of the 1995 Mekong Agreement. Because it is not always possible to attribute losses to any one particular dam in a cascade, a procedure may be required to ensure that all projects contribute to mitigation measures, particularly for major impacts on the communities that have their livelihoods affected. The extent of such contributions would depend on the scope, extent and valuation of potential impacts.

- Adaptive management: Given uncertainty, there will be a need for adaptive management. In the past, potentially significant impacts have often been omitted from concession agreements and power purchase agreements, as operations were dictated predominantly by power dispatch arrangements, i.e. the needs of the power purchaser. Hence it will be necessary to include appropriate provisions for adaptive management in both concession agreements and power purchase agreements.
- Good practice and safe operations: Implementing designs, operation and maintenance regimes, and institutional arrangements according to international good practice and safety standards. It may also be useful to specify consistent minimum quality standards for the transfer of the assets at the end of the concession period.

11. Further to the above issues, a consistent approach to the safe passage of extreme floods through any proposed mainstream dam is required. Article 7 of the Mekong Agreement, which refers to the prevention and cessation of harmful effects, makes this obligatory. This includes consideration of scenarios for climate change affecting the long-term hydrology of the Mekong and extremes. Similarly a consistent approach to the safety of individual dams and any cascade as a whole is of paramount importance. Section 6 of the guidance refers to adopting commonly accepted international guidance on dam safety offered by the International Commission on Large Dams (ICOLD) and embodied in the World Bank Operational Policy (OP/BP 4.37) on the Safety of Dams.

12. The focus of this guidance is the 11 currently proposed series of low head dams spanning part or the entire mainstream channel in the Lower Mekong Basin in the Cambodian, Lao and Thai reaches of the Mekong mainstream. [3] Generally, most of these projects would form long reservoirs within the Mekong channel of up to 100 to 150 or so kilometres. Some have inundation outside the normal mainstream channel. These proposals include infrastructure for hydropower production that will be incorporated in the dam facilities, and river flows that will be returned to the Mekong immediately downstream. Strategies for power production that incorporate diversion of flows out of the main channel for substantial distances downstream of the dam are not covered. Guidance for abstraction of water at the dam-sites for additional purposes such as irrigation is not included.

[3] While Developers proposals for dams in the lower Mekong mainstream have not been finalized, generally they would vary in head between 6 m or more to 35-40 m. By comparison, the eight dams completed or under construction upstream in China vary from 67 m to 248 m head (for Jinghong and Xiaowan respectively).

2. Navigation

2.1 Background

13. Inland waterway transport is a vital link in the transport network not only between the MRC Member Countries, but also with PR China and the rest of the world. In the Upper Mekong Basin at least 260,000 tonnes of cargo per year is transported between Thailand and Yunnan province in China via the Lancang-Mekong River.

14. In addition to the Upper Mekong trade route, substantial growth in river trade has been experienced in the Lower Mekong Basin. Between 2002 and 2005, yearly container movements at Phnom Penh Port increased from 746 to 47,349 and the recent opening of Cai Mep port is expected to lead to significant further increases in trade.

15. In addition to the direct economic benefits of inland waterway transport, this water transport offers lower external costs than other modes. It is estimated that on the Yunnan-Bangkok multi-modal transport route, annual savings in fuel consumption with current transport volumes are about 4.5 million litres, corresponding with a reduction of 12,400 tons of CO_2-emissions. This is in addition to the reduction in vehicular traffic travelling through many villages, which causes local pollution and increased traffic accidents.

16. Article 9 of the 1995 Agreement mandates freedom of navigation along the Mekong River. Dams are required to ensure that they do not pose an additional obstacle to navigation. Whilst hydropower developments have the potential to pose a barrier to navigation, it is important to remember that they also offer the possibility of providing more reliable and consistent water depths that will facilitate larger vessel capacities operating on a year-round schedule. The most cost-effective and appropriate way to realise the benefits of inland waterway navigation in harmony with hydropower development is the construction of navigation locks.

17. It is also crucial to bear in mind the long-term nature of planning and investment for navigation locks. After dams, locks are the biggest and most expensive structures on a navigable river. It is almost impossible to adapt their width and depth once they have been constructed, although lengthening and building a second lock is possible. Lock dimensions must therefore accommodate predicted increases in river traffic with a view of up to 50 years in the future. In the Greater Mekong Subregion (GMS), it is difficult to predict exactly what the transport needs will be that far in the future when establishing standards for proposed lock dimensions, however, it will be safe to assume that the transportation of heavy cargo such as mined products, containerised waterborne transportation and the introduction of inland cruise vessels will inevitably increase in years to come and the size of ship locks needs to accommodate this expansion.

18. When proposing the exact dimensions for ship locks, it is imperative to know what the longitudinal depth profile of the Mekong River will be after proposed hydropower dam developments have been implemented. Comprehensive answers need to be informed by full knowledge on hydropower dam heights, location and operating levels which give the minimum and maximum water level that can be maintained in the backwater of the

dams; the extent of the free-flowing stretches of each hydropower reservoir; and the water level and the conditions of the navigation fairway that can be maintained in the free flowing stretches. This information, combined with future trade projections will define the optimal (maximum) ship dimensions. Then the optimal lock design can be established. For the proposed cascade of dams north of Vientiane part of this data will be available once the Optimisation Study of the Mekong Mainstream Hydropower Projects commissioned by the Government of Lao PDR is completed. Similar information is required for the proposed projects downstream of Vientiane. Nonetheless preliminary dimensions have been proposed in this design guidance.[4]

19. The MRC is currently preparing recommendations for Standard Specifications for Ship Locks on Mekong Mainstream Dams. Phase 1 includes a Review of International Ship Lock Dimensions and their Relevance to the Proposed Hydropower Developments on the Mekong Mainstream, and Phase 2, includes Standard Specifications for Construction and Operation of Navigation Locks.

2.2 Guidance for navigation lock design and operations

General requirements:

20. On stretches influenced by hydropower developments, the terms of reference of all the hydropower developments shall refer to the same definitions of Highest Operating Level (HOL), Normal Operating Level (NOL), and Lowest Operating Level (LOL)

21. On free-flowing stretches, the terms of reference shall be defined by reference to hydrological statistics specifying Lowest Navigable Level (LNL), Mean High Navigable Level (MNL), and Highest Navigable Level (HNL).

22. The ship locks must be capable of raising transiting vessels from the downstream hydropower development level to the upstream hydropower development or water level, or correspondingly, lower transiting vessels from the upstream hydropower development level to the downstream hydropower development or water level, during all periods of authorised navigation on the Mekong River.

23. The lockage, or raising and lowering operations, shall be performed in one or two consecutive steps, depending on the total maximum lift of the lock, using chambers designed and constructed for this purpose. The maximum head (difference between Highest Operating Level and Lowest Navigable Level or Lowest Operating Level if there is a backwater effect from a downstream development) of one chamber shall be 30m. Locations that require the ability to traverse a height greater than 30 metres should use two locks in a series (tandem) arrangement.

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[4] These recommendations are not applicable for the proposed Don Sahong Hydropower project. The Khone Falls form a physical barrier to navigation with severe environmental constraints. Moreover, the current capacity for navigation on this stretch of river is very limited for a distance of more than 100km upstream and downstream of the falls. In the near future, multi-modal hubs on either side of the falls offer a potential means of addressing the current limits to navigation in this area, however further investigation is needed to determine the best means of facilitating transport.

Dimensions and design vessel:

24. The following considerations are made when proposing lock dimensions:

- The longitudinal profile of the river and related potential navigability of the river (slope, width, discharge and bend radius) after hydropower development;
- The long-term economic potential of the region, and possibilities for waterborne transport and trade;
- The need for consistency with lock dimensions on the Lancang River in PR China; and
- The stipulations in the 2000 Quadrangle Agreement for Commercial Navigation between Lao PDR, Myanmar, PR China and Thailand, and the 1995 Mekong Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin between the four Lower Mekong Countries.

25. The MRC conducted a Review of International Ship Lock Dimensions and their Relevance to the Proposed Hydropower Developments on the Mekong Mainstream. This study was based on benchmarking with international experiences, recommendations by the International Inland Navigation Association (PIANC)[5], and assessments of Chinese waterway classifications in the case of rivers associated with hydropower developments.

26. Until the results of the Optimisation Study of proposed mainstream dams undertaken by the Government of Lao PDR are fully assessed, and further research on developing the most appropriate design vessel specification for Mekong navigation locks is conducted by MRC in 2009, the preliminary guidance offered for the dimensions of lock chambers is:

- Length: 120m
- Width: 12m
- Depth: 4m
- With provision for future doubling of the locks (if traffic increases) in a parallel set-up to a width of 24m.

27. In order to ensure that that the design of dams makes provision for subsequent increases in river navigation; it is strongly recommended that a parallel slot is reserved for a second lock on each dam to double capacity.

Lockage time and availability

28. Lockage time shall be a significant factor in determining the design. The objective shall be to develop an overall design that ensures lockage time is kept to a minimum; is consistent with safe operation; and fully takes into account the safe movement of vessels into and out of the locks.

[5] http://www.pianc.org/

29. The total time for a complete lockage (target lock cycle) by the design vessel through each lock complex shall not exceed 30 minutes for a one-step lock and 50 minutes for a two-step "tandem lock". All times are for a design vessel in fully laden condition.

30. The emptying/filling system shall be designed to conform to the requirements for maximum transit times and allow for the smooth and safe lockage of any type of boat smaller or equal to the dimensions of the design vessel. Regarding this objective, the design criterion shall be:

- Max hawser forces ≤ 1‰ x water displacement of the vessel (in tons).

31. The locks should be designed to operate at least 12 hours a day, every day of the year. Each lock complex shall be operational for at least 98 percent of its scheduled operating time during each year of its service life, excluding planned closures for scheduled maintenance.

32. Outages related to incidental breakdowns, unscheduled maintenance and other unexpected outages, such as those resulting from collisions, extreme weather conditions, or causes beyond human control shall not exceed 2 percent of the operating time each year.

33. Service outages for scheduled maintenance shall be on 9 consecutive days (one working week and the two weekends) each year, during the same period for the whole Mekong mainstream waterway. The official body in charge of navigation coordination along the Mekong River will be responsible for specifying the dates for servicing.

Location and alignment:

34. Hydraulics (currents), river morphology (sedimentation) and wind exposure must be taken into account when determining the location and alignment of locks.

35. Lock entry and exit by barges must be safe and easy, from both upstream and downstream sides. Especially downstream from the lock, cross currents produced by turbines and gates and local sedimentation have to be taken into account in the lock design.

36. Fine material sedimentation occurs just upstream and downstream of the lock. Adapted design is necessary to mitigate sedimentation; and maintenance by dredging has to be foreseen.

37. The lock sill-bottom level must include a safety margin (of at least 1m) to take into account bed incision downstream of the dam - in order to ensure sufficient draught over the entire life of the structures.

38. Each lock should have a straight alignment of at least 250 metres on both sides to allow for the safe entry and exit of vessels. This alignment should be separated from the main flow of the river at least 250 metres in both directions from the hydropower barrage.

Construction:

39. Navigation will need to be maintained to the maximum extent possible during construction for the size of vessels that currently use the Mekong mainstream. The MRC will provide an indication of the size of such vessels in a subsequent version of this preliminary design guidance. Where disruptions are unavoidable, alternative road transit routes around the blocked areas should be considered as a means of mitigating their impact.

Service life:

40. Each lock complex shall have a functional lifetime of 100 years, providing that a convenient and scheduled maintenance policy is applied. Some components of the lock may have a service life shorter than 100 years. These components shall be designed to allow for easy replacement. The minimum service life of the main components shall be as outlined below and financial provision made for replacement when needed:

- Metal structures: 50 years
- Hydraulic jacks: 15 years
- Ball bearings, pulleys, etc: 25 years
- Cables: 10 years
- Electrical equipment: 30 years

Expansion

41. The design of the locks system should include provision for the construction of a second line of locks. It is recommended the developer or hydropower dam operator be responsible for the construction of a second line of parallel locks when the number of lockages per year reaches at least 80 percent of the total maximum possible yearly lockages over a period of 3 successive years.

42. Specifically, the layout and alignment in the design drawings shall consider the location of the chambers, gates, approach structures, control buildings, and other elements, in order to facilitate the construction and operation of the second line of locks. The design shall include details explaining how the second line of locks would be built in a way that minimises construction costs and the distance between chamber centrelines to allow the use of the same navigational approach channels.

Chamber equipment:

43. Floating bollards and wall ladders should be installed at appropriate intervals on the inside of the chambers. Ladders should be recessed into lateral walls.

44. Considering the consequences of damage to the gates on the availability of the lock system, before the construction of a second line of locks, one gate protection device shall be provided inside the chamber. This device should be a fixed shock absorber protecting the downstream mask wall (above the downstream gate).

Design, operation, safety, and maintenance:

45. The developer shall prepare design and specifications for the locks to ensure they are functional and reliable. Important design objectives are to optimise operational efficiency and adhere to the minimum lock downtimes required for the maintenance or replacement of operating components.

46. The developer shall furnish a design that provides vehicular access to all aboveground structures for maintenance and operation, access for emergency response vehicles, and an overall layout for operating conditions that protects the safety of navigation in the locks.

47. The developer shall design, procure, install, and commission all plant necessary for the optimum control and function of the lock complexes. This shall include process control systems; visual, audio, and electronic surveillance systems; and command and control communication systems. These systems shall include the ability to communicate with other locks on the Mekong mainstream waterway as well as to provide real-time and historic monitoring of lock usage data, information from which must be accessible by the MRCS or authorized riparian administration agencies.

48. The developer shall provide designs to ensure durability; and that maintenance requirements are reduced to the lowest practical level. The HDO shall design systems with sufficient redundancies in critical components to allow maintenance and repair without adversely affecting lock-transiting operations.

49. The developer shall carry out all design work so as to reduce the environmental impact of possible breakdowns or failures and shall also include measures to mitigate any such impact.

50. The developer shall develop a strategy for emergency access to both sides of each lock complex in the event of flooding or the loss of the lock gates. A description of emergency access and egress routes should be included in the layout.

51. Lock gates and their manoeuvring devices shall be protected with water projection systems against the consequences of a fire inside the chamber.

52. Each lock complex shall provide for the lockage of vessels in a safe and efficient manner, without causing structural damage to vessels or lock facilities.

3. Fish Passage on Mainstream Dams

3.1 Background

53. The Mekong supports the world's largest inland fishery, with an average of approximately 2.6 million tonnes harvested annually from the Lower Mekong Basin (LMB). Fisheries supply 49-82 percent of the animal protein consumed in the LMB. The livelihood benefit of the resource, in terms of nutrition, income and employment is critical, particularly for millions of the rural poor, who have few other livelihood options. The Mekong is second only to the Amazon River in terms of biodiversity.

54. Migration between spawning and feeding habitats in different locations in the river system is an inherent part of the life history of many commercially important species in the Mekong. If these fish populations cannot complete their natural migrations, breeding is reduced and fish populations decline; in many cases this may lead to a complete loss of migratory fish.

55. Fish migration occurs in both an upstream and downstream direction. Upstream migration generally consists of adults, actively swimming to spawning grounds. Downstream migration involves all life history stages, including eggs and larvae which drift in the current, juveniles of limited swimming ability and adult fish. This varies depending on the species concerned.

56. Dams and falls are physical barriers across rivers that interrupt fish migrations both upstream and downstream. They also alter flow regimes in the river, which impacts on the capacity of fish to migrate.

57. Not all Mekong fish species will be affected by dams. Grouping Mekong fishes into different behavioural guilds shows the different levels of vulnerability to the effects of dams, as listed below. Table 1 shows fish guilds in the Mekong and the likely impact of mainstream dams on migrations. [6] Highly vulnerable guilds are shaded grey.

Table 1: Mekong Fish Guilds and Migration

Fish guilds in the Mekong	Likely impact of mainstream dams on migrations.
1. Rhithron resident guild (fish which live in headwaters)	Little or no impact
2. Migratory main channel (& tributaries) resident guild	Very high
3. Migratory main channel spawner guild	Very high

[6] MRC (2009) Modelling the cumulative effects of mainstream hydropower dams on migratory fish populations in the Lower Mekong Basin. MRC Technical Paper No 26, Mekong River Commission, Vientiane, Lao PDR.

4. Migratory main channel refuge seeker guild	Medium
5. Generalist guild	Little or no impact
6. Floodplain resident guild (Blackfish)	Little or no impact
7. Estuarine resident guild	Little or no impact (if dam is upstream of estuary and does not influence salinity dynamics in estuary).
8. Semi-anadromous guild (fish which move from estuarine areas to freshwater to breed)	High (for dams located in river mouths or lower potomon).
9. Catadromous guild (fish which migrate from freshwater to the sea to breed)	Very high
10. Marine guild	Little or no impact

58. The size of the migratory fish resource at risk from dams (guilds 2, 3, 8 and 9 above) on the Mekong mainstream has been estimated at 0.7-1.6 million tonnes per year (equivalent to approximately 30-60 percent of the annual catch in the Mekong). The analysis also indicates a first sale value for the resource of US$1.4 – 3 billion per year. This is a conservative estimate, because it does not take into account the economic benefits that flow through the economy from the trade and processing of fish products.

51. Movement of fish past the barriers may be possible only if effective fishways can be designed to accommodate the biology and numbers of migratory fishes in the Mekong. On hydropower dams (or any dams greater than approximately six metres in height), fish ladders or natural fish passages are unlikely to be effective for upstream migration. Fish lifts or fish locks are theoretically a possibility, but the technology has not yet been successfully applied elsewhere in the world, and the systems would not be able to cope with the large volumes of migratory fish in the Mekong. Problems are also encountered for downstream migration, mainly because of the mortality of fish passing through turbines and over spillways. Consequently, a number of different options for fish passage upstream and downstream need to be considered for the range of species, volume of migrations and flow conditions encountered at a dam site.

3.2 Guidance on fish passage design and operation

General:

59. The following section provides preliminary guidance on fish passage design and operation for developers planning dams for the mainstream of the Mekong. The guidance have been developed by the Mekong River Commission Secretariat, based on extensive consultation and review of dams around the world, their impact on fisheries, and measures developed to facilitate fish movement past dams.

60. Fish passage facilities for both upstream and downstream passage must be incorporated into all dams on the mainstream.

61. The developer should provide effective fish passage upstream and downstream. Effective fish passage is usually defined as "providing safe passage for 95% of the target species under all flow conditions." [7] The success rate for fish passage both upstream and downstream necessary to ensure continued population viability can be refined for the particular species concerned, based on its life history and the number of dams the species may have to pass to complete its life-cycle. [8]

62. Where fish passage rates are unlikely to be adequate to maintain viable populations, the developers must develop and propose mitigation options as one element of compensation programs for lost fisheries resources.

63. Consideration should be given to multiple systems at each site to cater for the large number of species and high biomass, especially given the variable flow regime and lack of biological knowledge on behaviour of migrating species.

Planning and design phase

64. The planning and design of the fishways should be fully integrated into the dam design concept from the earliest stages of planning. Many aspects of dam design need to be integrated with fish behaviour and fish passage facilities, including the dam axis; abutments; training walls; gate design; hydro draft tubes; and sill level in tailwaters. These elements need to be designed to ensure fish are guided to the fishways by creating flows that are laminar and parallel with the river centreline and by minimising lateral and rolling flows. Numeric and physical models of the dam and adjacent river are necessary to accurately predict flow patterns, and hence dam and fish passage design.

65. Developers are encouraged to utilise best international practice in fish passage design and be aware of the outputs of the MRC Fisheries Programme and ensure that a "core expert group" is retained.

Biological/ecological:

66. Facilities should be designed to cater for the upstream and downstream movement of the most important species at any site, under the seasonal flow conditions during the periods when the species migrate. Target species should be selected based on considerations of commercial and livelihood importance, broad coverage of ecological guilds, as well as conservation of threatened species. [9]

67. The maximum standard length of the target species moving upstream will vary from around 20cm to more than 100cm. For downstream migration, the size will vary from

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[7] Thorncraft, G and Harris, J. 2000. Fish Passage and Fishways in New South Wales: A Status Report. Cooperative Research Centre for Freshwater Ecology (Australia). Technical Report 1/2000. 32 pp.

[8] See Halls, A. and Kshatriya, M. in press. Modelling the cumulative effects of mainstream hydropower dams on migratory fish populations in the lower Mekong basin; MRC Technical Series No. 25. Mekong River Commission, Vientiane.

[9] The Mekong Fisheries Programme is currently defining a list of target species.

eggs and larvae a few millimetres long, to adult fish. These variations will have significant implications for fish passage design, and will likely necessitate multiple systems at each site.

68. The preferences, tolerances and biological attributes of the target fish species relevant to successful movement through the facilities should be clearly established. Of particular importance are size at time of migration; swimming capabilities (prolonged and burst swimming speeds); depth and horizontal positioning in the river channel downstream or the impoundment upstream of the dam wall; diurnal movements; and cover, substrate and light preferences.[10]

69. The peak biomass likely to be using the facilities must be determined and the appropriate structure sizing of fishways, cycle time of fish locks and/or lifts, and water availability established.

70. Predation within the fish passages should be minimised. Therefore, predator-prey relationships within the target species and other species that may use the facilities, or benefit from the reduced fitness of fish that have traversed the pass, should be determined. Adequate shelter for smaller species while within the confines of the fishways should be considered, and actual residence time in the fishways should be minimised.

71. Fish exiting fishways both upstream and downstream should be sufficiently healthy to continue their natural patterns and migration routes. Direct and indirect mortality combined, as a result of movement through the fishways, should be less than 5 percent. Similarly, human fishing in the vicinity of the fishways should be managed to ensure mortality caused by fishing is not excessive.

Hydrology

72. The fishways should cater for the largest operational ranges practical, within the biological and hydrological requirements of the fish species concerned. As a guideline, fishways should be fully operational from minimum low season flow of up to the 1:20 year flood level.

73. Particular attention must be given to ensuring that the entrances to fishways effectively attract fish. This will require that adequate flows are available to attract fish to the entrances. Adequate flows must be directed through the fishways to ensure they function effectively in both the high and low flow seasons, and at all times are sufficient to ensure optimal effectiveness for fish passage targets. [11]

74. Dam and fish passage design should minimise fish injury or entrapment. Spillway design, aprons, stilling basins and dissipater design should seek to minimise fish injury, mortality and entrapment.

[10] Some of this information (e.g., prolonged and burst swimming speeds) may not be available, and developing it will require experimental facilities not currently available in the LMB region. Consequently, it may be necessary to use substitute data derived from surrogate species or estimated from field observations.

[11] For the low-head mainstream dams in the LMB it is expected that most of the water in the high season flow would be over the spillway, in which case flows down the fish passage will have no impact on energy generation.

Hydraulic environment

75. Fishway entrances should be:

- Sited to take maximum advantage of the hydraulic conditions created by spillways, outlets and channel structures. Conversely, the entrance should not be located where water velocities or turbulence are likely to hamper fish attraction to the facility.
- Suitably located to be accessed by fish over the full operational range of the fishway. Consequently, it may be necessary to have multiple entrances to the one fishway.
- Located where the morphology of the river, as well as the substrate and cover, promote fish attraction to the facility.

76. Spillways should be designed so that extra flows initiate and terminate adjacent to the fishway entrance(s) to maximise attraction to the fishways.

77. Fish attracted to the spillway need to be able to access the fishway entrance without needing to double back to find the entrance.

78. Fish exiting upstream fishways should not be drawn back over the spillway during overtopping. Exit conditions should be sufficient to provide stimulus for fish to exit the fishway. The combination of suitable attractive water flows, substrate and protection from predators is important.

79. Barrier screens should be designed to guide downstream moving fish away from turbines and towards the fish passage facilities. The screens must be sized to ensure that fish cannot pass through or become trapped within the mesh, and water velocities at the screens must be low enough to prevent fish being trapped against the mesh surface. Self-cleaning travelling or rotating screens should be used where there are high debris loads.

80. The use of fish friendly turbines should be investigated and adopted where feasible.

Operation

81. The period of captivity and interruption to the normal movements of the fish should be as short as possible.

82. Water quality should be maintained within any holding enclosures to ensure fish health. Oxygen levels should be maintained within the fishways at >5 ppm.

83. Where an environmental flow downstream of the dam is required, the appropriate volumes should be directed through the fishway as a first priority, thereby ensuring fish are attracted to the fishway entrance as well as maximising operating time.

84. Entrance slot velocities should be adjustable, such that feedback from monitoring and observation of fish behaviour can lead to optimisation of the fishway operation.

Monitoring and evaluation

85. Provisions for monitoring facilities at fishways are to be incorporated into the design and operation phase of environment management and monitoring programmes. This should include the ability to sample fish safely from the fishways as well as monitor fish movements and water quality.

86. Monitoring programmes should be established to quantify the effectiveness of the fishways. Determining their effectiveness requires sampling upstream of the dam wall, within the fishway, and downstream; such data will allow determination of the proportions of species and biomass attempting to migrate that successfully negotiated the fishway.

87. The monitoring programme should be funded by the developer for the duration of the concession period.

88. Developers should utilise a core group of international experts to assist with the design and implementation of the monitoring programme, with all expenses covered by the developer.

89. Developers should set aside contingency funds for modification of the fishway facilities, which may be identified as necessary based on the results of the monitoring programme as well as new information from other Mekong fishway programmes. The contingency fund is 20 percent of the initial cost of building the fishways. A guideline figure for the contingency fund should be replenished as it is drawn down, to ensure that funds are always available for modification works.

4. Sediment Transport and River Morphology

4.1 Background

90. Dams interrupt the natural continuity of sediment transport in river systems, inducing deposition within the reservoir and releasing sediment-starved water downstream, which typically produce channel adjustments and potentially reduce the tailwater. Deposition of sediment in reservoirs will shorten the reservoir's economic life and can interfere with reservoir functions, as well as increase pressure on the dam and increase backwater effects. Changes in either river flow or sediment load can also induce changes in the form and dimensions of alluvial channels downstream. [12]

91. Localized sediment deposition may also affect critical mechanical equipment at the dam, such as reservoir flood gates and turbine intakes. Sediment that builds up in the wrong location can compromise the safe working of the dam, its ability to pass the design flood without overtopping and the longevity of the turbines.

Reservoir sedimentation

92. By creating flat-water conditions or at a minimum, reducing velocity and stream gradient, reservoirs cause sediment to deposit from faster inflowing waters. The percentage of sediment thus trapped by a reservoir is referred to as its trap efficiency. [13]

93. Side tributaries that join the Mekong mainstream part way down the proposed reservoirs may also form deltas that will intrude into the reservoirs. In particular, side tributaries that are steep may be expected to carry significant amounts of large bed material onto the deltas. [14] The Mekong River, slowed by the downstream dams, will have trouble transporting the material downstream. Depending on the presence/absence of bedrock, the reservoir banks opposite the tributary deltas may erode rapidly.

94. When predicting rates of sediment accumulation in reservoirs it is important to account for trap efficiency (and how it may change over time) and to account for dams upstream of the reservoir in question that would reduce sediment delivery to the reservoir.

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[12] Rivers transport sediment as well as water, and their channels adjust to both independent variables: flow regime and sediment load, their magnitude, timing, and sediment calibre.

[13] For larger storage dams the bedload consisting of the gravel and sand fraction of the load carried along the river bed, trap efficiency is generally 100% (except in very small diversion or low-head navigation dams), but for suspended load (the sand, silt, and clay carried in suspension in the water column) trap efficiency varies roughly with the ratio of reservoir capacity to river inflow: large storage reservoirs typically approach 100 percent, small reservoirs less, and trap efficiency can decrease over time as sedimentation reduces capacity.

[14] Dams on tributaries draining rapidly-eroding mountainous regions may have larger sediment loads relative to flow than mainstream dams, and thus may experience more rapid sedimentation and also will reduce sediment loads (and associated delivery of nutrients) to the mainstream system.

Sediment starvation and downstream channel response

95. As dams trap sediment, they release waters with reduced sediment loads, sometimes called sediment-starved or "hungry" water. [15] These flows downstream of the dam possess more energy to transport sediment, but may have little or no sediment, depending on the dam type and reservoir characteristics. The excess energy of these flows can typically cause erosion of the channel bed and banks for some years following dam construction, resulting in incision (down-cutting of the bed) and coarsening of the bed material until equilibrium is reached and the material cannot be moved by the flows. However, if coarse materials are not present in the bed, or if gravel mining has already extracted a large part of these coarse materials, bed incision cannot be stopped and can reach significant depths of many meters.

96. Environmental consequences of hungry water include loss of physical infrastructure due to undermining by incision, lowering of alluvial water tables due to incision, loss of habitats due to coarsening of the bed and simplification of channel form as bars and other features are lost to erosion, and loss of cover to fish species that depend on turbid waters to hide from predators. Reducing sediment delivery to coastal regions causes depletion of sandy beaches (normally receiving sediment from river discharges), resulting in increased rates of coastal erosion. Reduced delivery of sediment to river deltas causes land loss (as natural subsidence is no longer compensated by fresh sediment deposition) and increased erosion of delta shorelines. [16]

97. On the Mekong River system, sediment starvation can be expected to result in loss of large bedforms and gravel/sand bars, and ultimately increased bank erosion in alluvial reaches, reducing channel complexity and affecting habitats formed of loose alluvium. Changes in sediment delivery may affect the Tonle Sap and exacerbate existing problems of coastal erosion in the Mekong Delta caused by sand extraction from the river channel.

98. To predict the likely effects of the planned dams on the Mekong River and tributaries requires estimating sediment yields from various regions in the basin, locating planned reservoirs within the drainage network, estimating trap efficiencies of the reservoirs, and developing an approximate sediment balance by reach in the mainstream and tributaries. Likely effects of these changes in sediment supply can be projected at a reconnaissance level by comparing to other river systems worldwide, to highlight the potential impacts anticipated by reach as a basis for planning mitigation measures. More detailed predictions could be made for specific reaches based on models and detailed input data sets.

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[15] Hungry water does not occur universally below dams, because reservoirs may reduce flood peaks downstream in some cases, so reducing transport energy such that the river is unable to transport sediment derived from tributaries and other sources downstream of the dam. These sediments can accumulate in the bed, causing aggradation or fining of bed material.

[16] As documented in deltas worldwide including the Nile and Mississippi.

4.1.1 Strategies to sustain reservoir capacity

Sediment routing

99. Sediment routing involves passing sediment through or around reservoirs to avoid net sedimentation, distinct from flushing, which involves removing sediments already accumulated. Sediments in river flows are concentrated in space (e.g., greater concentrations near the bottom of the water column) and time (e.g., greater concentrations during large floods and seasonally). Sediment routing attempts to isolate the sediment-laden portion of the flow from other waters.

100. Sediment pass-through delivers sediment to downstream reaches in essentially similar concentrations and seasonal high flows as prevailed in the pre-dam regime. [17]

101. Venting turbidity currents through the low-level outlets of the dam is a special type of sediment pass-through. Turbidity (or density) currents have different density than the reservoir waters they enter (due to higher sediment concentrations and/or lower temperature) and pass through the reservoir along its bottom without mixing with the reservoir waters. These currents can pass through the reservoir to the upstream face of the dam, where they can block operation of low-level outlets. However, if low-level outlets are open when turbidity currents arrive at the dam, it may be possible to pass much of the turbid water downstream (more than half is passed at some dams).

Sediment bypass

102. Sediment Bypass involves diverting sediment-laden water into a channel or tunnel from the river channel upstream of the reservoir, bypassing the reservoir and delivering the sediment to the channel below the dam. This approach has many advantages, in that it preserves continuity of sediment transport to downstream reaches and avoids sedimentation problems in the reservoir itself. However, it is possible only in situations where the geometry of the river and reservoir are favourable, for example, where the reservoir occupies a river bend whose orientation is such that a short-cut tunnel can be created from the channel above the reservoir to the channel below the dam. [18]

Sediment flushing

103. Sediment flushing (or sluicing) involves drawing down a reservoir and allowing accumulated sediments to pass through low-level outlets into the downstream channel. As with sediment pass-through, the reservoir temporarily behaves like a reach of river, transporting sediments through the dam. Unlike sediment pass-through or bypassing, which preserve the pre-dam timing of sediment loads, sediment flushing releases more concentrated sediment discharges over shorter time periods, and changes the temporal

[17] Examples of successful sediment pass-through include the old Aswan Dam on the Nile, the Bhatgurk Reservoir on the Yeluard River, India, and a series of hydropower reservoirs along the River Inn along the Austrian-Bavarian border.

[18] Examples are the Nagle Reservoir in South Africa and the Nan-Hwa Reservoir in Taiwan, where sediment-charged waters flow through the bypass under gravity. Sediment is successfully bypassed around Miwa Dam on the Tenryu River in Japan, despite the modest river bend in the reservoir.

pattern of sediment release. If flushing is implemented during flood season, greater river flows are available to flush sediment and move it downstream.

104. For convenience and safety, flushing is often implemented during base flow periods, because if problems occur with low-level outlets (such as debris jams), they can more easily be fixed, and because there is less risk to personnel working during the non-flood months. However, base flow flushing may have the greatest environmental effects because the sediment release is out-of-phase with the seasons when higher sediment concentrations occur naturally, such that organisms are not adapted to such concentrations and deposits in the channel downstream may remain for months until mobilized by the next high flow.

105. Flushing can only be done on reservoirs that can be drawn down regularly, eliminating large reservoirs that must maintain year-to-year carryover storage. Flushing is most effective when the low-level outlets are large and can pass sediment-transporting flows without creating backwater conditions. Outlets should be located as low in the dam as possible and as wide as possible. Such outlets should be included as an integral part of the dam during design because it is rarely possible to retrofit existing dams with low-level outlets without compromising structural integrity.

106. In flushing sediments accumulated over a period of years, the currents typically erode a channel into the sediment deposits. The channel typically progresses upstream by regressive (headcut) erosion, in which the over-steep reach of channel migrates upstream through the accumulated deposits. The accumulated sediment flanking this channel may remain largely intact, except as locally undercut by the channelized flow. Or it may slump into the channel, limiting the reservoir capacity restored. As cohesive sediments settle in the reservoir, they may consolidate in place and resist entrainment by flushing flows. Mechanically disturbing such sediments and exposing them to flushing flows can increase the amount of sediment removed by flushing. Backwater can induce deposition of coarse sediment at the upstream end of the impoundment, such that some reservoirs whose capacity is maintained by annual flushing still experience growth of coarse sediment deltas at their upstream ends. [19]

107. The water released downstream by flushing typically has very high sediment concentrations (typically exceeding 100 g/L, commonly as much as 1000g/L) during the channel formation phase, when accumulated sediments are actively eroded. Once a channel is established through the reservoir, sediment released may be limited mostly to inflowing sediment. The high sediment concentrations can have severe environmental effects in the downstream channel. These include clogging of fish gills, and clogging of water intakes. Deposition of sediments can fill pools; clog interstices of gravel and cobble-beds; and smother other important habitats; and can reduce channel capacity by

[19] One strategy (employed in Jensanpei Reservoir in Taiwan and some Chinese reservoirs) is to leave the reservoir drawn down with outlets open for the first part of the flood season, allowing high flows to flush accumulated sediments and to pass-through incoming sediments, then to close gates and begin impounding water during the second half of the flood season, during which time sediment accumulates in the reservoir. This approach (a combination of flushing and pass-through) maintains reservoir capacity and is well-suited to sites where demand of reservoir functions is seasonal only.

aggradation. Moreover, fine-grained reservoir sediments are commonly rich in organic material, which when released in a pulse can produce anoxia downstream and result in extensive fish kills.

108. In rivers with highly variable flow regime, flushed sediments may remain in the downstream channel for months or even years until remobilized by high sediment-transporting flows. [20]

Mechanical removal

109. Where hydraulic flushing is not possible, sediments accumulated in reservoirs can be removed mechanically, by dredging or drawing down the reservoir and excavating dry. Sediment accumulations near intake structures or navigation channels are commonly dredged. Dredging can be done using hydraulic suction driven by a pump, siphons (in which the head difference is used to drive the sediment slurry through a pipeline), or mechanical clamshell or bucket ladder dredges. Reservoirs that are seasonally dry or that can be dewatered are commonly dredged using conventional heavy equipment. The relative advantages of each method will depend on specific site characteristics. Key considerations include location of suitable disposal areas nearby, distances and vertical uphill haul required, and logistics of transferring sediment from reservoir deposit to truck, or in some cases, slurry pipeline. Mechanical removal can be expensive, typically \$5-\$15/m^3.

Sediment traps

110. Deposition of sediment is inevitable when the continuity of sediment transport is interrupted by impoundments. Recognizing this, one approach to partially addressing sedimentation in reservoirs is to induce deposition upstream of the reservoir itself, in sediment traps specifically designed for ease of routine sediment removal. Such traps can be designed to receive high sediment-concentration flow from lower parts of the water column, while flow with lower concentrations is diverted around the trap. The key concept is recognizing the inevitability of sediment deposition and constructing an environment that induces sedimentation where it is easier to deal with. Unless they are very large, such traps will capture mostly coarser fractions of the load, which can potentially be used as construction aggregate. [21]

111. Low head, run-of-river dams will trap less sediment than dams with large seasonal storages because fine sediment is more readily held in suspension, and routing or flushing of fine and coarse sediment can be carried out more easily and efficiently.

[20] As occurred during a series of dry years in California rivers in the late 1980s.
[21] As done in the Shikma Reservoir, Israel

4.1.2 Mitigating downstream sediment starvation

Sediment augmentation downstream of dams

112. To mitigate for loss of sediment supply due to trapping in upstream dams, sediment may be deliberately added to the downstream channel. [22] Sediment augmentation can be undertaken as injection of sediment into the channel below the dam, for redistribution by flows into natural features, or by placing gravel in sites where it is expected to provide habitat benefits immediately, typically as artificial spawning riffles. Injected sediments must be transported before they provide benefits and added in sufficient quantities so they are not dispersed upon mobilization. Artificial riffles, by contrast, function as habitat immediately but may be lost upon mobilization of the bed. They are probably best suited to sites downstream of large dams that eliminate/reduce major floods.

113. Sediment augmentation programs should take into account not only the sediment starvation from trapping by the dam, but also reduced sediment transport capacity from dam-induced reductions in flood magnitude and downstream sediment sources such as tributaries. Moreover, sediment transport capacity is likely to change as finer gravel and sand is added to the coarsened pavement layer, because even the coarser fraction of the sediment mixture becomes more mobile as a result of the addition of finer sediments.

114. The source of sediment used in augmentation should be identified. The most sustainable source is deposits trapped by the reservoir itself, which can be excavated from the reservoir delta and either trucked, barged, or slurried to the channel below the dam. [23]

115. Most sediment augmentation to date has involved coarse sediments, gravels and sands, either for their direct habitat benefits or for their role in channel structure. However, the ecological effects of sediment augmentation needed to be considered as part of the environment flow assessment process (see section 5.3 on environment flow assessment).[24]

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[22] The practice is extensive in western North America and northern Europe, with most cases having the objective to restore habitat degraded by hungry water, notably to replace gravels needed for spawning by salmonids (salmon and trout). Of the more than 100 such projects on 22 rivers in the Sacramento-San Joaquin River system in California involving over 500,000 m^3 of imported gravel, all sought principally to improve salmonid habitat, and only one involved quantities equivalent to or exceeding annual sediment transport capacities. However, the largest sediment augmentation project to date, on the River Rhine below the Iffezheim Dam, is to prevent infrastructure damage from channel incision. An average of 170,000m3 of gravel and sand, equivalent to the annual sediment transport capacity of the regulated river is added annually.

[23] Most sediment augmentation projects to date take sediments from other sources, such as gravel mines in the nearby floodplain (or, on the Ain River in France, from excavation of a side channel isolated by incision of the mainstream channel) because these sources are logistically easier and cheaper. Many reservoir deltas are in remote locations with poor access, thus more expensive as sources of sediment, or they are within designated recreation areas, which would normally prohibit industrial activities such as aggregate mining. An exception is the Middle American River in California, where sediment accumulation in Ralston Reservoir was interfering with dam operation. To restore reservoir capacity and augment sediment supply downstream, sediment was mechanically removed the reservoir and placed as gravel bars downstream, which have been gradually eroded by subsequent high flows. To compensate for a six-fold decrease in sediment load of the Colorado River below Glen Canyon Dam, the US Bureau of Reclamation proposes to dredge the delta of a tributary to the reservoir and to move the sediment by slurry pipeline to join the channel downstream of the dam.

[24] On environmental effect of sediment starvation below Glen Canyon Dam is loss of turbidity which native fish are adapted. The proposed sediment augmentation program includes a sand component to rebuild beaches and sand bars, plus fine sediment to produce turbidity during the months when the river naturally ran muddy.

4.1.3 Managing sediment in a cascade of dams

116. The sediment management regime needs to be coordinated for any cascade of dams. Spreadsheet models are needed to keep track of likely effect of upstream dams on sediment delivery to downstream dams and channel reaches using estimates of sediment yield by tributary catchment and estimating trap efficiency based on capacity-inflow ratios.

117. More broadly the morphological equilibrium of the Mekong River should be maintained and the susceptibility of the Mekong River to morphological change needs to be thoroughly assessed for each dam, as well as for the whole cascade of dams.

118. General principles for considering that management of sediment in dam cascades include the following:

i. The inter-relationships between hydraulics, river morphology and ecology need to be considered in design stages (individual dams) and when assessing the cumulative effect of sediment changes due to operation of a cascade of dams.

ii. Consideration can be given to whether dam developments should be avoided in reaches susceptible to severe morphological change.

iii. To minimise morphological change up-stream and down-stream of dams, and to sustaining reservoir capacity, dams need to be transparent to sediment transport, as much as possible.

iv. When considering the effects of mainstream dams on sediment transport and channel form/stability, it is important to consider effects of dam-induced changes in sediment transport from tributaries.

119. Consideration can be given by the concerned governments to include quality standards related to sediment and river morphology protection works in Concession Agreements. For example, for the transfer of assets at the end of the concession period, in particular the maximum extent of sedimentation in the reservoir. Also to require the dam owner to set aside contingency funds, to be held in reserve, in case unexpected expenditures for future bank protection works.

4.2 Guidance on sediment management and river morphology

59. The following section provides preliminary guidance on sediment management and river morphology for developers proposing mainstream dams in the Lower Mekong.

General requirements

120. Developers should design mainstream dams to pass fine suspended sediment and coarse bedload material in a way that most closely mimics the natural timing of sediment transport dynamics in the river.

121. Dams and intake structures should be designed to minimise the deposition and entrainment of sediment near the dam ensure long-term safe operation. Particular care

should be taken to avoid sediment deposition that poses risks for the safe working of the flood passage capacity of the dam.

122. Owners / operators should develop and implement a sediment monitoring programme. This would routinely monitor reservoir sedimentation, particularly for deposition at the head of the reservoirs during the operation phase, and take and adjust mitigation actions when needed.

123. All planned sediment management strategies should be thoroughly evaluated and subject to independent expert review for their likely effectiveness and impact prior to implementation at the developer's expense. [25]

Site Selection and Design

124. Developers should consider alternative dam sites at the feasibility stage (within the general location), with a view to select sites whose natural attributes, combined with the hydraulics of the river flow at the site best facilitate passage of sediment.

125. Natural channel features such as bends upstream of the proposed dam sites should be reviewed in the design stage. The potential of such bends to focus the bed load on the inside of the bend during high flow periods, and thereby reduce sediment problems at the proposed turbine intake locations should be considered. Dam layouts, including the location of the turbine intakes, low level outlet and spillway gates should be planned accordingly.

126. The dam should be designed to allow for sediment routing (pass-through) and periodic drawdown to enhance sediment flushing. Sediment bypass channels and sediment traps may be considered as additional strategies for sediment management.

127. Developers should employ the best possible technology for sediment investigation and modelling of sediment transport in 3-dimensional flow environments to assess how sediment deposition (and downstream erosion) problems can be minimised. In this respect:

i. Mobile bed physical hydraulic models should be used (ideally at feasibility, but if not at the detailed design stage) because of their strength in simulating the complex nature of the hydraulic performance and flow passage past the dams and critical structures.

ii. One focus in modelling should be minimising deposition at or near the spillway gates, and on minimising entrainment of sediment through the turbines (in addition to hydraulic modelling of fish passages, as noted previously in section 3, paragraph 64).

[25] The concerned government agencies would be advised of the independent experts the developers would engage. This is similar to the Dam Safety Panel as described in Section 6.

iii. Physical hydraulic modelling with mobile bed simulation should also be used to clarify locations where scour and deposition will be most severe, and to identify practical mitigation solutions.

iv. Detailed scenarios for reservoir sediment deposition and scour should be developed in the detailed design phase, based on an understanding of factors such as the extent of the flooded areas of the future reservoirs, their seasonal fluctuations, and presence of bed rock outcrops and the influence of tributaries.

v. An approximate assessment of the depth of the deposits at the head of the reservoirs should be established.

vi. Predicted locations where future development of mid-channel islands and future changes to the river thalwegs will occur should be identified.

128. Appropriate gates should be incorporated into the dam design to allow sediment pass-through and periodic sediment flushing:

i. The dam design should include not only bottom gates to pass/flush the sediment, but also releases from mid-level gates (or spillways) and to allow dilution of the highly concentrated bottom waters that are released . [26]

ii. Large bottom gates need to be included in the dam design for pass-through of density currents and flushing of coarse sediment. Bottom gates should be located as low in the dam as possible, as wide as possible, and in sufficient number.

iii. Fail-safe provisions, such as stop logs or additional gates, for dewatering the structures immediately upstream and immediately downstream of the bottom gates should be provided, in order for cleanout in the event of blockage.

Dam operation

129. Use of the bottom flow gates should be optimized to pass course sediment in both dry and wet seasons, also taking into account the need to avoid sediment problems with operation of turbine intakes.

130. Seasonal drawdown of the reservoir to minimum operating levels and opening of gates to allow sediment pass-through should be carried out when sediment concentrations and sediment transport rates are high (e.g. passing of suspended sediment from the start of, or early in the flood season before larger flood flows to limit settlement in the reservoir).

131. For periodic flushing of fine sediment and flushing of coarse bed material:

i. All sediment flushing should be planned and carried out in coordination with the operators of other dams in the cascade.

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[26] For some proposed mainstream dams there may not be enough vertical room to have mid-level gates, at the best the dams will house the flood (spillway) gates and some large bottom outlet gates. Additionally, a portion of the fine sediments will be entrained and pass the dam via the turbine flows.

ii. Flushing of fine sediments should be routinely carried out every year. Less frequent flushing may result in consolidation of fine materials on the reservoir bed, making future flushing efforts technically difficult and costly.

iii. Where it is possible to manage course and fine sediments separately, flushing of coarse sediment should be carried out after flushing of fine material considering 'environmentally friendly flushing' techniques described in paragraphs that follow later in this section.

iv. For the most effective flushing of coarse bed material, the reservoir should be drawn down to the maximum extent, at least every 2 to 5 years. Sediment monitoring (as described later in this Section) should be used to decide the frequency.

132. Where hydraulic flushing is not possible, or effective, alternatives to removing sediments accumulated in the reservoir should be considered including mechanical removal by dredging in critical areas, or in combination with the use of sediment traps.

133. Bottom-gates should be opened regularly to prevent accumulation of sediment directly behind the gates. This is to ensure that gates can be opened in an emergency and to prevent excessive accumulation behind the dam wall that could endanger structural stability.

'Environmentally friendly flushing' for sediment

134. The sediment concentration of water released during flushing operations should be controlled and monitored to prevent negative impacts on downstream ecology (high sediment concentrations can lead to fish mortality and smothering of spawning areas – see also Section 5 on environmental flows).

135. A maximum allowable downstream sediment concentration should be established based on ecological assessments. An initial limit can be based on the natural maximum sediment concentrations occurring during the flood season.

Monitoring and management

136. Monitoring and mitigation is needed that would include monitoring for (i) deposition of sediment at the head of each reservoir, and (ii) the scour of sediment that will occur initially downstream of dams. [27]

137. Annual topographic and bathymetric surveys should be undertaken, and the results mapped, to establish rates of sediment accumulation or scour.

138. Deep holes in the reservoir reach that were previously present in the river bed should be monitored, to establish rates of infilling.

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[27] Build ups of several meters of bed load material, extending over many kilometres of river channel at the headwater zone of each reservoir are likely. This may occur in a relatively short period of years, given the small amount of proposed storage in relation to the annual transport of bed load and suspended load.

139. River banks along the new flood level line should be monitored to establish rates of erosion. Reaches associated with formation of (1) new mid-channel islands at the head of reservoirs, and (2) positions where tributary sediment deposits start intruding into reservoirs should be emphasised, as there may be scour associated with changes in these reaches.

140. The developers / owner should be responsible to provide river bank erosion control with structures such as gabions if needed, for situations affected by changes in river channel position in the reservoir zones. See also paragraph, 119 that relates to government consideration to have dam owners to set aside contingency funds, in case additional expenditures for bank protection works are needed to arrest problems attributed to the operation of the dam – or to provide an undertaking in the Concession Agreement to ensure that sufficient financial resources are available for such work.

5. Water Quality and Aquatic Ecology

5.1 Background

141. Hydropower operations influence temporal flow patterns of rivers, which in turn, can influence instream water quality and the health, functioning and productivity of riverine ecosystems and flood plain ecosystems.

142. Healthy riverine ecosystems support the livelihoods of many people living along the banks of Mekong River (e.g. nutrition and income). At the same time they provide a variety of "ecosystem services" that contribute to water resource and water quality protection. River floodplains, wetlands and riparian vegetation trap silt and nutrients, provide fertile soils, and protect the upland areas from flooding and erosion. The regulation of river flow affects the complex food-web and aquatic ecosystem dynamics that support fish productivity, especially changes in flow pulses.

143. Impacts on dams on riverine water quality and aquatic ecology are interrelated. The degree and significance of the impacts depends on many factors, especially the volume of the reservoir impoundment in relation to river flows, water retention times and the depth of the impoundment and the patterns of land use in catchments.

144. The focus of this guidance is the current proposals for a series of low-head dams that would span part of, or the entire mainstream channel in the Lower Mekong Basin. The changes to water quality in the long reservoirs that will be formed behind these dams (mainly in the existing river channel) may be less than changes that might occur in large, deeper storage dams, such as those in the Lancang-Mekong portion of the basin in China. This is due to the short retention time of the water in the proposed impoundments of the mainstream dams in the lower basin (expected to be in the range of about four days). But it also depends on the amount of mixing that occurs between water column above and below the dead water levels and the number of dams.

145. Potentially, the more significant impacts of these dams will be related to physical and chemical water quality parameters (such as in relation to sediment concentrations in water released from the dam), which will impact on downstream aquatic ecology and the associated river morphology that results in aquatic ecosystem habitat changes.

146. Water related diseases should be foreseen and prevented at all potential dam sites in the mainstream. A particular concern is the known presence of the parasitic and eye disease schistosomiasis, at the proposed locations of the Ban Koum, Lat Sua, Don Sahong and Stung Treng projects.

Water Quality

147. Water quality is one of the environmental factors to be considered as part of the project-specific EIAs. Water quality parameters to be considered are generally cited in national regulations and include temperature, concentration of dissolved oxygen, PH,

phosphorus, nitrogen, biological oxygen demand and faecal coliform bacteria concentrations.[28]

148. Overall the water quality and the ecological heath of the Lower Mekong River Basin in its present unregulated state ranges from high to good quality (See MRC Technical Paper no. 19 and MRC Technical Paper no. 20). The MRC Procedures on Water Quality and the associated Technical Guidelines that are currently under development express the wish of Member Countries to maintain acceptable/good water quality of the Mekong River. The Technical Guidelines will provide criteria and thresholds to determine acceptable/good water quality considering the protection of human health as well as aquatic life. These standards would provide valuable guidance to assess river flows including run-of-river impoundments.[29]

Water quality in reservoirs

149. Stagnant water in impoundments behind dams can lead to a stratification of the water in the reservoir during parts of the year, with cold water at the bottom and warmer water at the top. In deeper impoundments the temperature difference can be as much as 5-10 degrees Celsius. This stratification phenomenon generally occurs during the dry season and lasts until the onset of the wet season. [30] The measured average dissolved oxygen concentration in the running water of the Mekong mainstream is in the range from 5.5-8.5 mg/l (1985-2005 data). Generally, lower oxygen concentrations can be observed in stagnant water during the dry season with high temperatures, but very low and anoxic conditions rarely occur unless the water is stratified such as in a deep impoundment. [31]

150. Another aspect of reservoir water quality is temperature alteration and variation which may affect fish species. Cold water released from the impoundment may affect organisms (e.g. affect fish species negatively and also pose the potential for thermal shock of irrigated crops if very cold water is withdrawn for irrigated agriculture with no provision for warming during conveyance).

[28] One example of water quality concern for high dams is low dissolved oxygen concentrations in the bottom waters of deep impoundments can kill fish and other aquatic life, both in the impoundment and downstream tailwater.
[29] Some modifications to the standards may be required to evaluate the water quality of any proposal for deep impoundments that produce stagnant water and thermal stratification.
[30] The surface of large reservoirs that typically provide seasonal or multi-annual storage will be heated by the sun. Because the cold water is heavier than the warm water and turbulence is low, there will be very limited mixing between the top and the bottom. Heavy rains and less heating from the sun will result in stronger mixing from the beginning of the wet season. Oxygen transportation from the atmosphere to the bottom takes place to a very limited extent during stratification. The natural processes of degradation of organic matter in the water and bottom sediments use oxygen and with no replenishment from the atmosphere. As a consequence the oxygen concentration in the bottom waters of the impoundment can become very low.
[31] The anoxic conditions caused by the stratification in an impoundment can lead to chemical changes in the water, e.g. nitrogen will be in its reduced form as ammonia and sulphate will be in its reduced from as hydrogen sulphide. Both compounds are toxic to aquatic life.

151. Subject to designs, the mainstream reservoirs proposed in the Lower Mekong Basin may have weak, large-scale turbulence associated with the flow of water through the reservoirs (rapid transit time for all reservoirs, speed of movement in the range 0.1 to 1 m/s). This would enhance the likelihood of mixing from surface to bottom and impacts on dissolved oxygen concentrations. Developers would need to verify the expected conditions in the EIAs that are prepared for each project.

Aquatic Ecology

152. Aquatic biodiversity and biodiversity in the riparian zones can be affected by impoundments for a range of reasons. The impoundment may block migration routes and lead to fragmentation of habitats (as discussed in Section 3). The hydrological changes and water quality changes may change habitats and the basis for ecosystems. The changes in hydrology, water quality and ecological conditions can change the ecological balance and pave the way for invasive and pest species affecting the biodiversity negatively.

153. Changes in the hydrological variability caused by impoundments may affect ecosystems and natural resources depending on the seasonal variability. Requirements to provide a flow regime or the environmental flows downstream of the impoundment may help to mitigate these adverse impacts and risks.

Environmental Flows – Downstream releases

154. A family of techniques called Environment Flow Assessments (EFA) are rapidly becoming a legal requirement in many countries. EFAs are an emerging practice in the Mekong and Asia more generally. [32] An environment flow assessment enables the government, developers and all stakeholders to consider how much water needs to be provided within rivers to maintain freshwater ecosystems and wetlands and their benefits, as well as impacts on riverine livelihoods. A comprehensive EFA also considers the river flows required for all water uses, expressed in terms of sufficient quality, quantity, timing and duration of river flows.

155. It widely recognized that the allocation of water for hydropower operations must take into account other beneficial uses of water. Today there is increasing recognition that modifications to river flows also need to be systematically balanced with the maintenance of essential water-dependent ecosystems. These ecosystems include not just river fauna and flora, but also the floodplains and wetlands watered by floods, groundwater-dependent ecosystems replenished through river seepage, and where applicable, estuaries. Flow assessments are becoming integrated with other tools such as EIA and water allocation planning for guiding decisions on sustainable water resource developments (balancing economic, social and environmental considerations) in hydropower development.

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[32] EFAs have grown out of what were formerly instream flow assessments developed since the 1970's, which were often more narrowly concerned with water availability and use. See also http://www.mrcmekong.org/annual_report/2006/pgress_environment.htm

156. Compensation and mitigation programs can also be developed on the basis of specific consideration of downstream issues, which are often different to upstream issues. Downstream impacts relate not only to the reduction in water flows, but also the associated transformation to the aquatic environment induced by the dam operation, including any daily and seasonal fluctuations in water levels. [33] Downstream issues that may form part of the compensation and mitigation programs for riverine resource losses may include reduction in fish, vegetables, vegetation, animal forage, firewood, timber for other uses and water supply for people, livestock and other uses from direct and indirect changes in the amount, quality, and timing of flows.

157. It is important to incorporate instream flow (environmental flow) considerations appropriately at all project stages (design, implementation, operation and monitoring). Good practice is to introduce the EFA concepts and methodologies at the EIA stage, either as a parallel study to inform the EIA, or as a sub-component of the EIA. [34]

Monitoring

158. The monitoring program for water quality and aquatic ecology (identified in environmental flow assessment or as part of the EIA) must be designed in compliance with national standards and maintain appropriate communication with concerned local governments, municipalities and agencies and downstream communities. This is important to enable stakeholders to provide essential feedback on whether:

- that targets specified in the monitoring programme (e.g. for water quality, wetlands protection, river morphology, impacts on fish habitat, etc.) are being achieved;
- the agreed-upon flow regime is being provided, in this case recognizing the run-of-river nature of the mainstream projects, the fact there may be peaking operation and taking into account the position of the dam in the potential cascade; and
- the operation of the reservoir and water releases downstream needs to be modified in the light of the observed responses.

159. Governments may also give consideration to requiring the dam owner to set aside contingency funds for additional water quality management measures, which may be identified as necessary based on the results of the water monitoring programme.

5.2 Guidance on water quality and aquatic ecology

160. The following section provides preliminary guidance on water quality and aquatic ecology for developers proposing mainstream dams in the Lower Mekong.

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[33] For some strategic or sensitive sites it may be necessary to declare that these will not be used for peaking power under any circumstances.

[34] Environment Flows: Concepts and Methodologies, World Bank. Water Resources And Environment, Technical Note C.1, 2003 plus other Notes in the series http://go.worldbank.org/8FF2N4VV60

General requirements

161. Optimization of operation of the reservoir to meet water quality objectives should aim to maintain sufficiently high levels of dissolved oxygen and sufficiently low levels of phosphorus, nitrogen, biological and oxygen demand. [35] Criteria for optimization can be derived from the MRC Technical Guidelines for Procedures on Water Quality. [36]

162. Developers should consider the impact of the dam and operating policies of any cascade on the 1995 Mekong Agreement as regard to water levels. Developers should demonstrate the projects meet the Mekong Agreement requirements (in the EIA). [37]

163. Minimum flow releases as well as restrictions on changes to natural variability need to be assessed using appropriate environmental flows assessment (EFA) techniques and approaches). [38]

164. Because the proposed mainstream dams are run-of-river with peaking or daily operation cycles for hydropower generation, the focus of the EFA would be on systematically looking at the localized impacts on river morphological processes, erosion and bank stability and aquatic ecosystem functions, as well as impacts on natural habitat such as riverine wetlands, fish habitat and related social and livelihood aspects.

165. Developers should utilise a core group of independent international experts to assist with the design and implementation of water quality compliance monitoring programmes and environmental flow assessment and provision, with all expenses covered by the developer.

Water quality monitoring

166. The monitoring systems need to be designed to facilitate the optimization of hydropower operation with respect to water quality and ecological health. The MRC Water Quality Monitoring Network and Ecological Health Monitoring Network can provide the general trends and status of the water quality and ecological health, whereas monitoring of impacts of hydropower operations need to have targeted and localized monitoring systems.

167. The monitoring and monitoring programme normally required as part of the Environment Management Plan (or environment mitigation and monitoring plan) should be funded by the developer for the construction phase, and the owner full duration of the concession period.

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[35] Other factors are faecal coliform bacteria concentrations that need to be managed.
[36] See http://www.mrcmekong.org/agreement_95/procedures-n-guidelines.htm and http://www.mrcmekong.org/publications/pubByCategory.asp?intCatalogID=7&strCatalog_NAME=Environment An example of a key parameter is the criteria for dissolved oxygen of 5 mg/l. The temperature is requested to be 'natural', which can be assessed based on historical data.
[37] http://www.mrcmekong.org/free_download/policies.htm Recognizing also that in a cascade situation, the approach to coordinate the operation of all dams is a major factor.
[38] This must consider the natural flow regime of the lower Mekong River Basin featuring four different flow seasons, the different characteristics of the river stretches and assessment of the consequences for the important ecosystems and natural resources potentially affected by the impoundment.

Environmental Flow assessment and provision

168. Developers should systematically assess the effect of combination of flow releases from the dam to address downstream impacts at different times of the year, also taking into account the position of the dam in the possible cascade series of dams. This should be done by introducing appropriate environmental flow assessment methodologies at the EIA and feasibility study stage, appropriate to the scale and significance of the flow changes, and referring to good practice techniques and methodologies. [39]

169. At the detailed design stage, the environmental flow regime would be established for average and low hydrology years (flow regime of quantity, quality, duration, and seasonality). An integrated approach should be used that takes into account the combined effect and coordination of water releases for electricity generation (i.e., turbine releases) sediment management (i.e., flushing, density current venting, etc. through low level outlets or partially open spillway gates), navigation and fish passage, as well as the relative dominance or influence of spillway releases on downstream conditions.

170. Developers should pay special attention to the possible the impact of rapid fluctuations in water levels downstream of the dam due to any daily releases for peak power generation and the ramping rates (hourly rate of change in releases, which in peaking operations, depends on how many generation units are brought on line at once, and how quickly).

171. Releases via the turbines and the spillway gates need to be ramped so change in water surface downstream (and upstream) is sufficiently slow to minimize adverse effects on downstream river bank stability and does not pose a public safety hazard. In particular, if the mainstream dams are proposed as peaking projects, with anticipated hourly fluctuations in water flows, it will be important to find agreement on satisfactory rates of ramping.

172. The environmental flow provisions and the monitoring arrangements should be incorporated in the Environmental Management Plan (EMP), or its equivalent, for both the construction and operation phases, which is to be reviewed and approved by the relevant national authorities.

Monitoring of environmental flow provision

173. The developer and operator should ensure the environmental flow considerations are adequately reflected in the operating policies for the reservoir and sediment management strategy. Good practice is to adaptively manage the downstream releases from the dam based on continuous review of the monitored results in accordance with the

[39] See IUCN Publication Flow: The Essentials of Environmental Flows http://www.iucn.org/about/work/programmes/water/wp_resources/wp_resources_toolkits/?1134/6 and Environment Flows: Concepts and Methodologies, World Bank. Water Resources And Environment, Technical Note C.1, 2003 plus other Notes in the series http://go.worldbank.org/8FF2N4VV60

environment management and monitoring plan (EMMP) for the operation phase, or its equivalent.

174. The monitoring arrangements for environmental flows should be integrated with the overall environment monitoring system for the operations stage of the project that comprehensively incorporates impact monitoring of all parameters (e.g. sediment monitoring, impact on wetlands, impact on fisheries habitat, impact on river morphology and water quality, and socio-economic aspects related to these effects, etc.). [40]

175. For the well-being of the natural aquatic downstream environment, the monitoring should provide an independent review of the flow release regime, including releases down the fish ladder and releases during daily cycling of the turbines for peak or daily generation and the daily water level changes. This should be reported, and submitted to government to check annually to ensure compliance with approved operating ranges. [41]

[40] A monitoring program is particularly important given the generally limited data and uncertainty in the links between flow and ecological response and other river dynamics.

[41] There are business reasons that may cause an operator to release smaller flows through the fish ladder than the licensed flow, so this independent assessment of compliance will be important.

6. Safety of Dams

6.1 Background

176. Dam safety is of paramount importance for the individual dams proposed on the mainstream of the Lower Mekong Basin, as well as the safety of any cascade as a whole.

177. The broader philosophy today is the safe design, construction and operation of dams depends on more than engineering factors. The approach to dam safety must recognize that failure of a dam is a complex process that can include human error in design, construction and operation, maintenance and monitoring stages. [42] A systematic approach and management framework that accounts for the complexities of operation of dams is fundamental to achieving and assuring dam safety.

178. The main thrust of the guidance in this section is to implement designs, operation and maintenance regimes, and institutional arrangements consistent with national requirements and international good practice for the safety of dams. Further, a consistent approach to the safe passage of extreme floods is required including consideration of flood return periods for design and operation of critical structures during both the construction phase and operation phase. Article 7 of the Mekong Agreement, which refers to the prevention and cessation of harmful effects, makes this obligatory.

Dam safety issues

179. Broader dam safety issues associated with characteristics of the proposed low-head dams on the Lower Mekong mainstream include the following:

- Operation of these low-head mainstream projects requires a pro-active approach to risk management, partly because there is so little storage in the reservoirs. Most of the proposed dams have in-channel reservoirs. As a consequence, rates of change of the water surface elevation in the reservoirs would sometimes be very fast. Reaction times of dam operations staff in emergencies will need to be quick, and there will typically be insufficient time to get clearance from senior management about actions during high flood events, load shedding during power line failures, and other unusual situations.

- Mechanical and electrical control equipment at the dams will need to be well conceived and designed as well as very thoroughly backed/doubled up, to ensure capability in emergencies. This applies especially to equipment such as that used to hoist spillway gates, and other facilities whose failure may cause overtopping of the dam.

- Comprehensive dam safety reviews need to be scheduled at least once every five years. The composition of the expert review team should consist of experienced electrical, mechanical, hydraulic, hydrological, structural and geotechnical engineers as well as social and environment experts, capable of independent thinking "outside the book". If possible, the team members should have participated previously in similar work. Dam

[42] ICOLD, Bulletin on Dam Safety Management, 2005.

safety reports should be copied to government, and follow-ups initiated to confirm that the recommended work was undertaken.

- Additional work should be undertaken by an expert mechanical/hydropower engineer, to assess the wear on the turbine impeller and control valve/wicket gates for the turbine, to assess wear from abrasion and likely losses of turbine efficiency.

6.1.1 World Bank Operational Policy on Safety of Dams

180. When the World Bank finances new dams it requires that experienced and competent professionals design and supervise construction. Also that the borrower adopts and implements dam safety measures through the project cycle (World Bank Operational Policy 4.37: Safety of Dams). [43] Operational Policy 4.37 also applies to existing dams. The World Bank Operational Policies (which are part of the World Bank "Safeguard Policies") [44] are widely accepted and applied by governments, industry, developers and dam owner / operators on World Bank-financed dam projects in Asia and worldwide.

181. The World Bank Operational Policy includes a requirement to establish a Dam Safety Panel consisting of three or more recognized international experts in different aspects of dam safety, who have no role in the design or operation of the dam. [45] For illustration purposes only, selected aspects of the World Bank OP/BP 4.37 are highlighted as follows:

- For the life of any dam, the owner is responsible for ensuring that the appropriate measures are taken and sufficient resources provided for the safety of the dam, irrespective of its funding sources or construction status.
- Reviews by the independent panel of experts of the investigation, design and construction of the dam and start of operations;
- A construction supervision and quality assurance plan, which normally covers the organization, staffing levels, procedures, equipment, and qualifications for the supervision of the construction of a new dam.
- An instrument plan, which is a detailed plan for the installation of instruments to monitor and record dam behaviour and related hydro meteorological, structural and seismic factors.
- An operation and maintenance (O&M) plan, which is a detailed plan that covers the organizational structure, staffing, technical expertise, and training required as well as the equipment and facilities needed to operate and maintain the dam. It includes but is not limited to O&M procedures and arrangements for O&M and funding, including

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[43] World Bank Safety of Dams Safeguard Policy: http://go.worldbank.org/6G6AB69P30
[44] All World Bank Safeguard Policies http://go.worldbank.org/WTA1ODE7T0
[45] The purpose of the Dam Safety Panel is to advise on matters relative to dam safety and other critical aspects of the dam, it's the appurtenant structures, the catchment area, the area surrounding the reservoir, and downstream areas. Good practice is to extend the panel composition and terms of reference beyond immediate Dam Safety concerns to cover such related areas impacting on safety as project formulation, technical design, construction procedures, and for water storage dams, associated works such as the power facilities, ship lifts, and fish ladders.

long-term maintenance and safety inspections. A preliminary plan is provided during the feasibility and detailed design stage. The plan is refined and completed during project implementation and the final plan is due not less than six months prior to initial filling of the reservoir.

- An emergency preparedness plan, which specifies the roles and responsibilities of all parties when dam failure is considered imminent, or when expected operational flow releases threatened downstream life, property, or economic operations that depend on river flow levels. The plan itself is prepared during implementation and is provided to the panel for review not later than one year before the projected initial filling of the reservoir. In particular, it is important to have a clear communication strategy to engage with stakeholders on dam safety issues and emergency preparedness activities that directly involve or affect them.

182. Developers and owner / operators will need to demonstrate how they will apply the entire OP/BP 4.37. Consideration should also be given to ensuring that relevant dam safety measures provided in this guidance are appropriately reflected in Concession Agreements.

6.1.2 Other information on the safety of dams

183. In addition to national standards and the World Bank Operational Policies applicable to dam safety, the International Commission on Large Dams (ICOLD) offers guidance on the safety of dams relevant to the Mekong. ICOLD has established a multi-country Technical Committee on Dam Safety (CODS) to prepare the ICOLD Bulletin on Dam Safety Management, which is updated and issued periodically.

184. The ICOLD Committee on Dam Safety (CODS) was established to develop and provide a practical, integrated approach that brings together inputs of all the various ICOLD Technical Committees. This addresses the wide range of interdependent factors that impact on the safe design and operation of dams. The broader principles embodied in the ICOLD Technical Bulletins, as stated by ICOLD, are: [46]

- The prime responsibility for dam safety should rest with the entity responsible for the dam (owner) and the activities that give rise to its operation. – i.e., the owner is responsible, which is consistent the World Bank Operational Policy 4.37.
- The level and government framework for the safety provides the overarching structures for dam safety assurance – i.e. abide by national laws.
- Effective leadership and management for safety should be established and sustained in organizations responsible for dam risks – i.e. from regulatory bodies to dam operators.

[46] ICOLD Bulletin 59 and Bulletin 130 on Risk Assessment in Dam Safety Management: A Reconnaissance of Benefits, Methods and Current Applications.

- Dams, reservoirs and activities that give rise to dam safety risks should compensate by yielding an overall benefit to society.
- Measures for controlling dam safety should ensure that no individual bears an unacceptable risk.
- People, property and the environment, present and future, should be protected over the effects of dam failures and other reservoir woks.
- All reasonable practical measures should be taken to prevent and mitigate dam failures and accidental releases.
- Appropriate arrangements should be made for emergency preparedness and response for dam failure and accidental release.

185. A further consideration is dam break analysis of the proposed cascade of dams should be prepared and coordinated through concerned line agencies and MRCS.

6.2 Guidance on the safety of dams

186. The following section provides preliminary guidance for developers proposing mainstream dams on the Lower Mekong to ensure a consistent approach to safety of dams.

General requirements

187. Developers should base the approach to safe design, implementation and operation of proposed mainstream dams:

i. Relevant national standards that impact on different aspects of dam safety;

ii. International best practice, as embodied the World Bank Operational Policy 4.37 on the Safety of Dams; and,

iii. Periodic Technical Bulletins on the Safety of Dams issued by the International Commission on Large Dams (ICOLD) through the ICOLD Committee on Dam Safety (CODS).

Adopting international best practice

188. All aspects of the World Bank Operational Policy (OD/GP 4.37) for the safety of dams should be reflected by developers and operators, including required reviews by an independent panel of experts of the investigation, design and construction of the dam and start of operations and sub-plans (i) a construction supervision plan (ii) a quality assurance plan (iii) an instrument plan (iv) an operation and maintenance (O&M) plan, and (v) an emergency preparedness plan (EPP).

189. Developers, owners and operators should reflect the relevant International Commission on Large Dams (ICOLD) Dam Safety Bulletins in the project design, as well as the approach to project construction and operation. [47]

190. In particular, developers / owners / operators should prepare and implement a Dam Safety Management System (DSMS) that reflects ICOLD guidance on establishing a systems approach to the management of dam safety. This starts from design and continues through to operation. The DSMS incorporates the production of an annual report on dam safety during the operation phase that is submitted to governments and made public.

191. Developers and operators should ensure there is full and effective consultation with local communities and local government authorities and all concerned organizations and agencies, especially with regard to the emergency preparedness plan (EPP). The EPP should include a communication strategy to reach and involve all concerned and affected people (i) in preparation of the EPP, and (ii) in training or capacity building to implement the EPP, and (iii) responding to any issues concerning annual Dam Safety reports.

192. Developers and owner/operators should be responsible to check for periodic updates of the World Bank Operational Policy (OD/GP 4.37) as well as updates, or new Technical Bulletins on the Safety of Dams issued by the International Commission on Large Dams (ICOLD). At minimum, this check for updates should be routinely done in preparation of the annual Dam Safety report.

193. Developers and owners should be responsible for all cost associated with implementing all aspects of this guidance on the safety of dams. Developers / owners / operators should clearly detail all such costs in the project budgets for the design, implementation and operation stages.

[47] ICOLD Bulletin 59 and Bulletin 130 on Risk Assessment in Dam Safety Management: A Reconnaissance of Benefits, Methods and Current Applications.