REOPTIMIZING GLOBAL IRRIGATION SYSTEMS TO RESTORE FLOODPLAIN ECOSYSTEMS AND HUMAN LIVELIHOODS

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ABSTRACT

The ultimate objective of the *Global Survey* project is to restore natural ecological functions, environmental services and the livelihoods they support to the downstream floodplains below the major dams of the world. There are today some 45,000 large dams operating in the world, the majority of which were built after World War II, and two-thirds of which are located in developing countries. Designed with a focus on economic and social benefits, these hydraulic projects have endangered the livelihoods of local communities who depend on rivers and their floodplains for their nutrition and livelihoods. In addition, they have caused pervasive damage to freshwater, riparian and estuarine ecosystems that support these human production systems.

Yet recent studies suggest that such damage to natural systems and riparian communities is often unnecessary and can be reversed by modifying the operations of these facilities in ways that do not significantly reduce—and can sometimes even enhance—their irrigation, power generation, and flood control benefits. Building on the potential of this recent work, NHI and its partners are undertaking a global inventory of the most promising opportunities and techniques to modify the operations of major water storage and diversion projects.

INTRODUCTION AND PROJECT OBJECTIVES

Background

The World Commission on Dams (WCD 2000) has chronicled both the economic benefits attributable to the 45,000 large dams built in 160 countries in the past half-century and the damage they have caused to water-dependent ecosystems and human production systems. Building on that work, the *Global Survey* will assess the feasibility of re-optimizing the major irrigation, power and flood management systems to restore a substantial measure of the lost ecosystem functions and human livelihoods in the downstream floodplains, without substantially diminishing the economic benefits for which the dams were constructed.

With few exceptions, the world's hydraulic infrastructure projects have been operated for a limited set of economic objectives and without consideration of the environmental consequences. Yet riverine ecosystems and the myriad species they support are shaped by, and dependent on, the timing, magnitude, duration, and frequency of flow patterns. Excessive changes in any one of these four variables can lead to the collapse of entire fisheries and ecosystems. The consequences for the downstream river basin can be

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profound. In most cases highly dynamic riverine systems are transformed by dams into static water delivery channels, reducing the diversity of habitat and species. Elimination of annual floods deprives riparian forest and wetlands of periodic inundation, effectively disconnecting the river from its productive floodplain habitats. Seasonal inflows of freshwater and nutrients into the ocean are diminished, disrupting the estuarine hydrodynamics that are the engine for the exceptional biological fertility at the freshwater/salt water interface: native fisheries suffer in the face of exotic invaders, seasonal natural and cultivated food sources are lost, pastoral use of the floodplain becomes impossible, game species are displaced, groundwater levels decline, and recreational and aesthetic values of a living river basin disappear.

Yet there are a number of water management techniques that can be employed to create substantial flexibility in how these dams and diversions are operated, opening up possibilities to restore lost ecological functions and processes. The *Global Survey* will pursue two converging lines of analysis:

(1) Identify the river reaches and floodplains downstream of major dams where restoration of periodic floodplain inundations in a managed fashion—emulating the natural hydrograph—would produce the greatest benefits in terms of restored aquatic ecosystems and human livelihoods and other land uses dependent upon natural groundwater recharge. To this end, the project is devising a rapid assessment tool to identify the best prospects for reoptimization. The objective of this reconnaissance level tool is to demonstrate that the number of dams that are good prospects for beneficial reoperation is far larger than has heretofore been realized and to thereby induce larger investments in the development of implementable reoptimization plans for the most promising facilities.

(2) Develop a "toolkit" of improved water management techniques that can provide the necessary flexibility in reservoir storage and release patterns to enable environmental flow regimes to be re-established. The types of water management techniques that can be applied to enable beneficial reoperation depend on the purpose served by the dam. We discuss this toolbox of techniques below.

Note that it is more accurate to describe the objective of the project as *reoptimization* of water management systems, rather than *reoperation,* because the techniques that we wish to explicate are those that can allow dams to improve their environmental performance while *continuing* to provide the water supply, power and flood control benefits for which they were initially constructed.

In recent years, increasing attention has been paid to the ecological benefits of reoperating dams to store and release water in a pattern that more closely resembles natural flow conditions with their seasonal variability (Acreman 2003). The aiming point is to operate the reservoir more as a run-of-the-river facility and less as a storage facility. This work defines the environmental water *demands* for the system. However, relatively little attention has been paid so far to techniques enabling these dams to make such environmental flow releases a permanent operational feature without reallocating water from economic to environmental uses. This may be regarded as the environmental water *supply* side of the system. This project is intended to fill that information gap.

The practicality of reoptimization ultimately reduces to the question of whether enough of the pre-development ecological and human production benefits can be restored to justify the costs of reoptimization, from the vantage point of full social accounting. Additional limiting factors – and hence cost-centers – include:

i) the difficulties in re-establishing sediment processes downstream of dams (which serve as sediment traps) that may irreversibly transform the morphology of floodplains and deltas;
ii) the intervening floodplain development that will constrain the magnitude of flood events that can be re-established; and
iii) the physical limits of the dam and reservoir.

It is also significant that some reoperation techniques, particularly conjunctive water management, can increase the stored water yield and thus create new value in the system that can offset the costs of reoptimization.

The best prospects for reoperation will emerge where the floodplain benefits converge with the technical potential for dams to release environmental flows. Preliminary work suggests that we will find those circumstances in China, South Asia, Southeast Asia (the Mekong system), Brazil, West Africa and Southern Africa, among other regions. The number of dams that will be evaluated will be illustrative rather than exhaustive. The next section of this paper sets out the threshold considerations in selecting the dams that will be assessed for their reoperation potential.

Project Phases

The project envisions three phases. In the current and first phase, the project endeavors to identify 2-6 dams that are especially promising candidates for reoperation. The goal of the second phase is to develop concrete reoperation plans for these facilities. This will involve much more detailed and intensive analysis and modeling of operational alternatives. The third and final phase involves implementation of the reoperation plans by the dam operators and government departments.

DAM SELECTION CRITERIA

The database that we are constructing currently contains more than 500 dams. From this list, we intend to apply the consideration factors described herein to select ten to twenty dam systems for a reconnaissance level of assessment of reoptimization feasibility and benefit. As noted above, to make releases for environmental flow restoration possible, it is necessary to create flexibility in how these dams store and release water for irrigation, power generation and flood control. In this process, we will evaluate the technical, socio-economic, and legal/institutional feasibility of applying specific water management techniques to generate that operational flexibility. Several other pragmatic factors will

also bear on the selection of water management systems for reoptimization evaluation. The results of the analysis will be findings and recommendations on how reoperating plans might be developed for the most promising of these dams.
There are five interrelated factors to consider in selecting major water management systems for reoptimization evaluation. These are:

1) The hydrophysical, socio-economic, legal/institutional and political requisites for successful reoptimization;
2) The potential for rich restoration benefits in the downstream floodplain;
3) The availability and sufficiency of the requisite data;
4) Willing partners; and
5) Geographic considerations

The Hydrophysical, Socio-Economic, Legal/Institutional and Political Requisites for Successful Reoptimization

Large dams have been built for three main purposes in all regions of the world, although about 20% serve multiple functions (WCD, 2000). The purpose of the reservoir determines the operating characteristics and the extent to which the reservoir stores and releases water on a schedule that distorts natural flows. Since the objective of this project is to find reservoirs that can be reoperated without impairing their economic uses, the purposes of the reservoir will usually determine the types of techniques that can be applied to create the operational flexibility that can enable environmental flows to be maintained as a permanent operational feature.

- **Water supply reservoirs for irrigation** constitute half of the world's large dams, with the largest number in China, India, Pakistan, and the United States (WCD, 2000). These dams generally provide seasonal storage and in some cases inter-annual storage of water to buffer the variations in natural runoff. There are a variety of techniques for changing the management of irrigation water in ways that increase the storage and release flexibility. Irrigation projects that were built to counteract pre-existing groundwater depletion give rise to the possibility of conjunctive water management and the integration of surface and groundwater management. This type of storage flexibility may enable a considerable degree of environmental flow restoration (Purkey et al., 1998). Other options include reducing storage requirements through techniques to reduce physical losses to the system through better on-farm management and retiring waterlogged and salinized lands.

- **Hydropower reservoirs** store water to create hydrologic "head" for power production either at the dam or at some point downstream. Some of these facilities operate, more or less, on a run-of the-river mode where the reservoir is used simply to create the hydrologic head rather than to store water. Generally, these are facilities where the capacity of the reservoir is small relative to the annual flow of the river.

However, most hydropower reservoirs store and release water on a pattern to generate power during times of highest demand (peak power facilities). Large storage, relative to flow, is developed specifically to counteract seasonal variation in flows. Hydropower is particularly suited for meeting peaks because can be switched on very fast – unlike thermal power stations which need warm-up period) Electrical demands generally peak during particular times of day when, for instance, lights are turned on the evening or air conditioners are turned on in the later afternoon, and during particular seasons, such as summer for cooling or winter for heating. The inflow patterns are generally out of phase with these release patterns, creating unnatural flow patterns that can be highly disruptive to downstream ecosystems and floodplain livelihoods. If power reservoirs can be operated to release water at the same rate as the inflow into the reservoir, they can merely pass the natural hydrograph through the reservoir without disrupting stream flows. Thus, the goal is to convert storage reservoirs into run-of-the-river facilities to the extent feasible.

For facilities that follow the load curve, the major challenge is to investigate ways in which the role of the hydrodam in the mix of generators feeding the grid can be changed to allow the dam to operate as a base load rather than peak load facility so that daily and flow fluctuations can be avoided, and seasonal fluctuations can be synchronized with runoff. These "run of the river" facilities are not wholly, benign, however. They do intercept sediment flows, which are essential to the downstream eco-morphology, and they adversely affect temperatures and other water quality parameters.

- **Flood control reservoirs** capture the peak flow events and release this water more slowly after the storm passes. While disruptive of the natural hydrograph, flood control facilities can most easily be operated to permit seasonal inundation of floodplains for environmental and floodplain production benefits.

  The reoptimization goal with flood control facilities consists of creating conditions under which a larger fraction of the peak flow events can be allowed to pass through into the downstream floodplain. Thus, facilities designed to control a 20-year flood event might be reoperated to only control the 50-year flood events. Land uses in the floodplain will need to be modified to accommodate this periodic inundation. If the land use constraint is immutable, such as larger human settlements, high-value structures such as roads or bridges, or permanent crops such as orchards, it may be that increased inundation of the floodplain is simply not feasible. Facilities with such downstream characteristics may not be suitable for reoperation.

SUMMARY OF TECHNIQUES FOR REOPTIMIZATION

To summarize, the current list of techniques, organized according the main purpose of the dam, are these:

Irrigation dams

- Integrating groundwater and surface storage (conjunctive water management)
- Aquifer recharge and recovery (groundwater banking)
- Reductions in physical losses from irrigation systems (reducing evaporative losses in water conveyance and applications, reducing deep percolation to salty aquifers, etc.)
- Relocating points of diversion and return flow
- Water transfer arrangements
- Retiring waterlogged or salinized lands

Hydroelectric dams

- Changing the role and function of the hydrodam in the mix of generation facilities for the grid
- Substitution of daily peaking facilities
- Re-regulation reservoirs downstream of hydroelectric dams
- Pumped storage facilities to reduce the need to operate dams to follow electrical load curves
- Better coordination of cascades of dams to permit more flexible operation

Flood control

- Flood easements
- Flood routing and storage in retention basins
- Levee setbacks

All dams

- Building sluice gates that pass sediment downstream

The feasibility of each of these techniques will also depend upon whether certain physical, economic and legal/institutional conditions exist. For instance:

- For conjunctive management of surface and groundwater storage in the irrigation setting, the *physical requisites* may include the existence of dewatered aquifers with appropriate physical characteristics in the irrigation command area (due to pre-existing or current groundwater pumping), reservoirs that periodically spill water for flood control purposes, and the ability to connect the two. The Yellow River basin in China and the San Joaquin River basin in California are two settings in which these conditions are known to exist, but they are likely to be found in many places around the world. The *economic requisites* may consist of the ability of the farmers to afford conjunctively managed water. The *legal and institutional* requisites may revolve around who owns and can extract surface water stored in aquifers and whether water rights and entitlements are sufficiently well-defined and enforceable to enable water transfer arrangements to take place.

- To change the role that hydropower generators play in meeting the peak daily or seasonal demands of the grid to which it is attached, two strategies may be envisioned. Either those peak demands can be met by other hydropower dams, or by other types of generators, such as gas-fired turbines, which are generally quite suitable for peak power production. Both of these alternatives will have economic (and social and environmental) consequences , which may or may not make them feasible. Both may or may not be accomplishable by interconnecting existing electrical grids, and that in turn may or may not be legally or institutionally feasible. To take the first alternative as an example, a frequent occurrence around the world is that a cascade of hydropower dams is built on the same river and feeds into the same grid. Typically, one of those dams (not necessarily the terminal one, but likely one of the larger ones) effectively controls flows through the cascade and into the downstream floodplain. Modeling can reveal the extent to which it would be feasible to reoperate that dam to improve environmental flows (as a primary operational objective) and then reoperate some or all of the other dams in the cascade to make up for the peak power production lost in the targeted dam.

Moreover, the very goal of reoptimization will require analytical tools to weigh competing objectives and to design alternative operation protocols. For example, to balance the productive objectives of a multipurpose dam against the competing socio-economic and environmental objectives of uses in the downstream floodplain, it may be useful to develop a model that simulates the interactions between alternative operation scenarios and resulting biophysical and socio-economic processes, such as food production possibilities related to the extent of flood in an area of recession agriculture. This allows for a concrete analysis of the best overall scenario that can optimize outcomes with minimal trade-offs among competing uses. An optimization analysis and dam management protocol has been in place since 1997 at Manantali dam in the Senegal River Basin, and has allowed for the design of yearly artificial flood to protect recessional agriculture (IRD 2004). Such a tool could be enhanced to explicitly incorporate ecological objectives.

While the *Global Survey* will concern itself mostly with the physical factors that determine the feasibility of beneficial reoptimization, it will also consider the array of other factors that make reoptimization implementable. We have already alluded to some of the socio-economic, legal, institutional, and political requisites in the discussion above. Important such enabling factors include:

- The extent of economic subsidies to existing uses of large dams. Such subsidies affect the costs and benefits of displacing a portion of existing uses to accommodate environmental flow releases. Where irrigation or power generation subsidies are large and the benefits of environmental flows are appreciable, reoperation may be attractive from the standpoint of net social benefits.

- The affordability of the measures necessary to remove structures, resettle populations or obtain flood easements, and the willingness of public agencies to pay these costs.

- Laws and institutions at the national and local level, e.g., well-defined and enforceable water rights or entitlements.

- Additional legal/ institutional and political requisites may have to do with whether the codes authorize eminent domain in these circumstances and whether the authorized government agencies are willing to exercise that power.

There are also a number of political factors that cannot be ignored. Dams in countries where the planning process is impervious and impermeable, where official corruption is too substantial, where proposals from NGOs have little traction, or where civil conflict is rampant are probably not good candidates for this work.

By distilling the requisites for successful application of reoperation techniques that can be applied to these types of water management systems, we can construct a rapid assessment tool for selecting those that warrant the investment of larger resources to evaluate their potential. We have constructed such a tool in the form of a decision tree. It is attached to this paper in Appendix.

THE POTENTIAL FOR RICH RESTORATION BENEFITS IN THE DOWNSTREAM FLOODPLAIN

The project will concentrate on those downstream river reaches where flow restoration will produce the largest ecological and human livelihood benefits. River reaches that supported the richest array of native species before development, and suffered the greatest loses as a result of development, are presumptively the ones that would provide the richest benefits if flows could be restored.

Unfortunately, however, there is a paucity of data on baseline conditions before dam construction that would permit comparisons with conditions after construction. Some analytical surrogate for biodiversity losses, such as the depletion of fish species and abundance, will need to be developed. Similarly, the analyses of hydrologic and biologic alteration of rivers are reported at the basin scale, not at the scale of the river segments immediately downstream of particular dam sites. This scale limitation will permit us to draw conclusions regarding generalized impacts only. Cumulative effects of cascades of dams are another complication.

In these circumstances, the benefits of reoperating a single facility are less clear. Moreover, as noted again below, displaced human livelihoods may not be recoverable and some physical effects of dams are irreversible, such as morphological changes in stream channels and deltas.

In general, we will assume that the reaches of rivers that nourish (or could nourish) broad alluvial floodplains, broad alluvial valleys (such as those associated with savannas in Africa and flood prone semi-tropic basins in Asia), wetlands systems, deltas and estuaries are the most important from a biodiversity and human production system standpoint. These tend to be found in the lower reaches of the rivers which are affected by the large storage dams that control freshwater flows in to estuaries and/or block migration of anadromous species. Floodplains are areas of high biodiversity and provide important habitat for riverine fish (Ward 1998; Welcomme 1979). Based on research conducted mainly in the tropics, scientists have described a 'flood pulse advantage' in which rivers that are connected to functioning floodplains produce a significantly greater biomass of fish per unit area than do rivers disconnected from floodplains or lentic water bodies, such as reservoirs (Bayley 1991).

THE AVAILABLITY AND SUFFICIENCY OF REQUISITE DATA

The data requirements for this project are driven by the selection criteria that are chosen, and the availability of the necessary data itself becomes a criterion for screening projects for more detailed examination. Under the time and resource constraints of this project, we will necessarily rely on information that has already been developed and expert opinion, with additional limited fieldwork.

WILLING PARTNERS

The active participation of the national agencies that plan, regulate, manage and operate the dams and their water management systems is indispensable. That is because these are the repositories of the data and technical expertise necessary to evaluate reoptimization potential, and because the results are much more likely to be implemented if these national agencies take early ownership in the program. The willingness of the key government officials to cooperate in the reoptimization evaluation is therefore a threshold selection criteria.

The practical necessity of working with government agencies in the affected countries also suggests that we work in countries that have already displayed some predisposition or inclination to consider environmental flows in the operation of dams. To date environmental flow methodologies have been applied in 52 countries, albeit often on a very limited basis (Tharme, 2003). The developing countries noted are:

- Brazil
- Cambodia
- Cameroon
- Chile

- India
- Indonesia
- Kenya
- Lesotho
- Mali
- Mauritania
- Mexico
- Mozambique
- Namibia
- Nigeria
- Pakistan
- Senegal
- South Africa
- Tanzania
- Turkey
- Zambia
- Zimbabwe

In addition, China has indicated a strong interest in dam reoptimization to improve environmental flows.

There is also an important role for in-country NGOs in suggesting reoperation strategies, providing information, opening doors with government collaborators, and creating a favorable climate of public opinion for the consideration of dam reoptimization. NGOs may also play a key role, due to their extensive local knowledge, in assessing the potential for natural resource and human livelihood benefits from re-establishing more natural flow regimes in the floodplains downstream of the major dams.

Incidentally, there is also an important role to be played by the intergovernmental agencies in this project. The World Bank has become keenly interested in this project. The Global Environmental Facility has also indicated an interest.

GEOGRAPHIC CONSIDERATIONS

We will emphasize countries where development assistance is most likely to be available for dam reoptimization projects: dam reoptimization, even when substantially maintaining the current economic uses, will usually not be free of cost. While reoperation strategies that also augment water supplies such as can be accomplished with conjunctive water management may pay for themselves, in many cases the environmental restoration and human livelihood benefits will not generate a revenue stream that can compensate the costs of dam reoperation. Thus, while on the full social accounting ledger, dam reoperation may often be "cost-effective", some external source of funding will usually be necessary to implement reoperation plans. Also, we wish to identify lost ecological processes that affect human livelihoods. These losses disproportionately affect subsistence users of the watershed. For both of these reasons, the project is inclined to emphasize dams in the developing world.

Moreover, the potential that successful reoperation experiments will be widely replicated may also be advanced by emphasizing the countries with the largest number of dams, on the assumption that successful experiments are most likely to be replicated in those same countries. Rebecca Tharme and the World Commission on Dams have published useful information on the numbers of major dams in various countries of the world, as illustrated in Table 1 (reprinted from Tharme 2003):

Table I. The top 20 countries worldwide by number of large dams (adapted from WCD, 2000)

	Country	ICOLD World Register of Dams 1998	Other sources	Percent of total dams
1	*China	1855	22 000	46.2
2	*United States	6375	6575	13.8
3	*India	4011	4291	9.0
4	*Japan	1077	2675	5.6
5	*Spain	1187	1196	2.5
6	Canada	793	793	1.7
7	South Korea	765	765	1.6
8	Turkey	625	625	1.3
9	Brazil	594	594	1.2
10	France	569	569	1.2
11	South Africa	539	539	1.1
12	Mexico	537	537	1.1
13	Italy	524	524	1.1
14	United Kingdom	517	517	1.1
15	Australia	486	486	1.0
16	Norway	335	335	0.7
17	Germany	311	311	0.7
18	Albania	306	306	0.6
19	Romania	246	246	0.5
20	Zimbabwe	213	213	0.4
	Others	3558	3558	7.0
	Total	**25 423**	**47 655**	**100.0**

*Estimates for the numbers of dams in these countries (particularly China) as well as for the Russian Federation, differ according to available data sources.
ICOLD, International Commission on Large Dams.

Combining this information with the bias toward developing countries, the preference for countries that have exhibited an interest in environmental flow restoration, and the political realities noted above, the following countries appear to warrant priority consideration:

Asia
China
India
Pakistan
Cambodia
Indonesia

Western Africa
Senegal

Mali
Mauritania
Cameroon
Nigeria

Eastern and Southern Africa
South Africa
Tanzania
Zambia
Kenya
Lesotho
Mozambique

Latin America
Brazil
Mexico

Eastern Europe and the Middle East
Turkey (and its downstream riparian Iraq?)
Albania
Romania

With all of these considerations in mind, we are defining country-specific or region-specific components of the project where we expect to be able to make the most headway. China promises to be fertile ground for this project, as the Minister of Water Resources himself will be leading the consortium of Chinese partner institutions, including the Institute for Water Resources and Hydropower Research, the Chinese Academy of Sciences, Tsinghua University (the leading technical university in the country), and others to investigate the prospects for reoptimization among major Chinese dams. The second promising area for intensive work is Western Africa, specifically, the Senegal, Niger and Volta River systems. The other areas targeted for special attention include Brazil and Southern Africa.

LIMITING FACTORS

Before concluding, it is important to acknowledge certain inherent limitations in what we can hope to achieve in this project, given certain physical constraints and limitations:

- The project cannot hope to restore the natural hydrograph in its entirety in developed rivers while substantially maintaining the current economic uses of these dams. At most, we can hope to restore the flood plain inundations that naturally occur every 2 or 5 or perhaps10 or even 25 years. But we generally cannot hope to restore the 50 year or 100 year events. That means that the ecological benefits associated with large flood events cannot be recaptured through dam reoperation.

- Even beneficial flow alternation will not restore the sediment transport and deposition processes necessary to restore downstream ecological conditions and floodplain productivity.

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- Floodplain encroachment by structures and land uses may limit the feasibility of controlled reintroduction of floodplain dynamics.

- The capacity of the release works to permit variability in streamflows may also constitute a physical constraint on reoperation.

OUTCOMES AND POLICY IMPLICATIONS

In a field dominated by conflict, stalemate and zero-sum thinking, the project offers a creative solution and a way to bridge the professional gulf between engineers and ecologists. Specifically, this work will lead to the pursuit of feasible restoration projects by the national governments and international assistance agencies. The results of NHI's *Global Survey* project will feed directly into the World Bank's Water Program and its stated preference for projects that improve the performance and use of existing dams (World Bank 2003). The project will also advance the Bank's environmental directive to integrate biodiversity concerns into large hydraulic infrastructure projects.

The project will also demonstrate and transfer a toolkit of techniques that can we used more widely by local conservation interests to effectively advocate for restoration initiatives far beyond the initial opportunities list that will emerge from this project. This will help implement two of the strategic priorities of the World Commission on Dams; first, the objective of restoring, improving, and optimizing the benefits from existing large dams and identifying opportunities for mitigation, restoration and enhancement; and secondly, the objective of sustaining the livelihoods of river-dependent communities by "releasing environmental flows to help maintain downstream ecosystem integrity and community livelihoods" (WCD, 2000). In addition, the NHI project will fill critical data gaps identified by the WCD as essential for strategic planning, namely improved understanding of the extent to which managed floods can offset the impacts of dams on downstream ecosystems and livelihoods, the effects of dams on downstream ecosystems, and techniques for improving the conjunctive management of surface and ground water.

Finally, this work will provide a concrete step forward in the implementation of measures to enhance the sustainability of major water management systems, such as those set forth in the International Hydropower Association's Sustainability Guidelines (2004). Indeed, the reoptimization toolkit and the set of demonstration cases developed under this project will open a path to many more opportunities in which the detrimental social and environmental impacts of major hydraulic infrastructure, including hydropower dams, are avoided or substantially mitigated.

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APPENDIX

Coarse Screening Tool to Identify Major Dams that Are Promising Candidates for Beneficial Reoperation

The technical considerations reflected in the template are of two types: (1) the physical attributes of the reservoir and the downstream channel/floodplain that make them good prospects for restoration of ecosystems and floodplain livelihoods, and (2) the physical attributes in the irrigation, electrical distribution or flood management system that are needed to apply the various improved management techniques. The simplified data requirements for performing this initial level of screening are summarized in Box 1. Boxes 2-3 present a routine for performing this type of screening.

Box 1: Data requirements for assessment of reoperation potential

The ability to assess a water management system for reoperation opportunities depends upon access to a wide variety information. Some of this data is easily obtainable in the form of the engineering specifications of system facilities (i.e. structures operated for water storage, conveyance, power generation, etc.) and hydrologic measurements (i.e. gauged discharge). However, other factors that are important in the assessment of reoperation strategies may be known only in a very general sense (e.g. existence of a dewatered aquifer) or may elude quantification altogether (e.g. degree of encroachment on the floodplain). Data requirements can be grouped into six main categories. In order of increasing difficulty to obtain, these are:

1) *Engineering specifications of the dam and reservoir*
- Purpose of dam/reservoir
- Volume/Surface Area/Elevation Relationships
- Height of dam
- Storage capacity
- Generating capacity
- Release works
- Operating authority

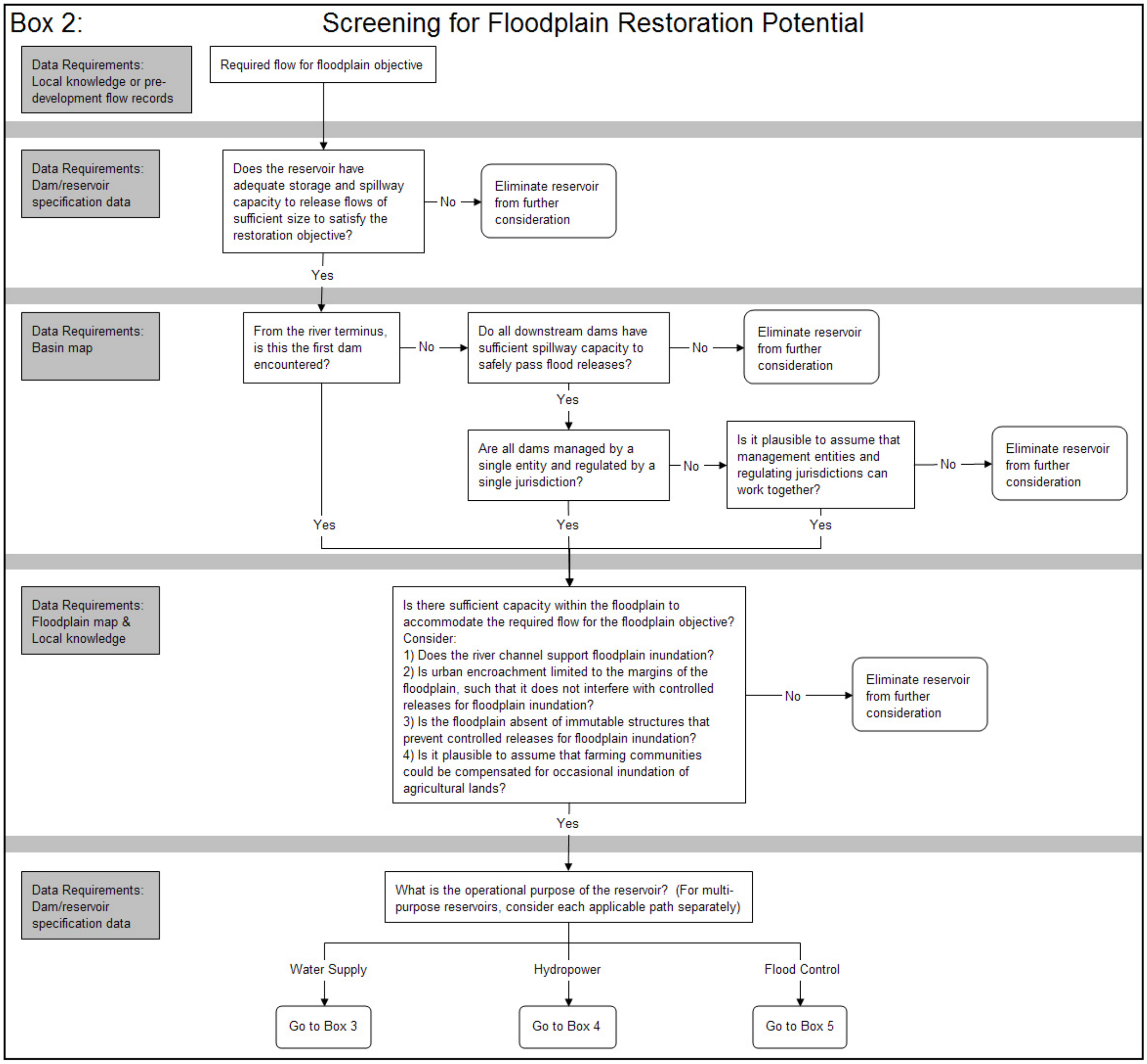
2) *Spatial relations of the floodplain and water service facilities within the watershed*
- Map of watershed indicating position of
  i. Reservoir(s)
  ii. Service area (i.e. cities, irrigated agriculture, etc)
  iii. Restoration target
- Map of floodplain indicating
  i. Position of immutable structures (e.g. roads, bridges, factories, hospitals, etc.)
  ii. Land use

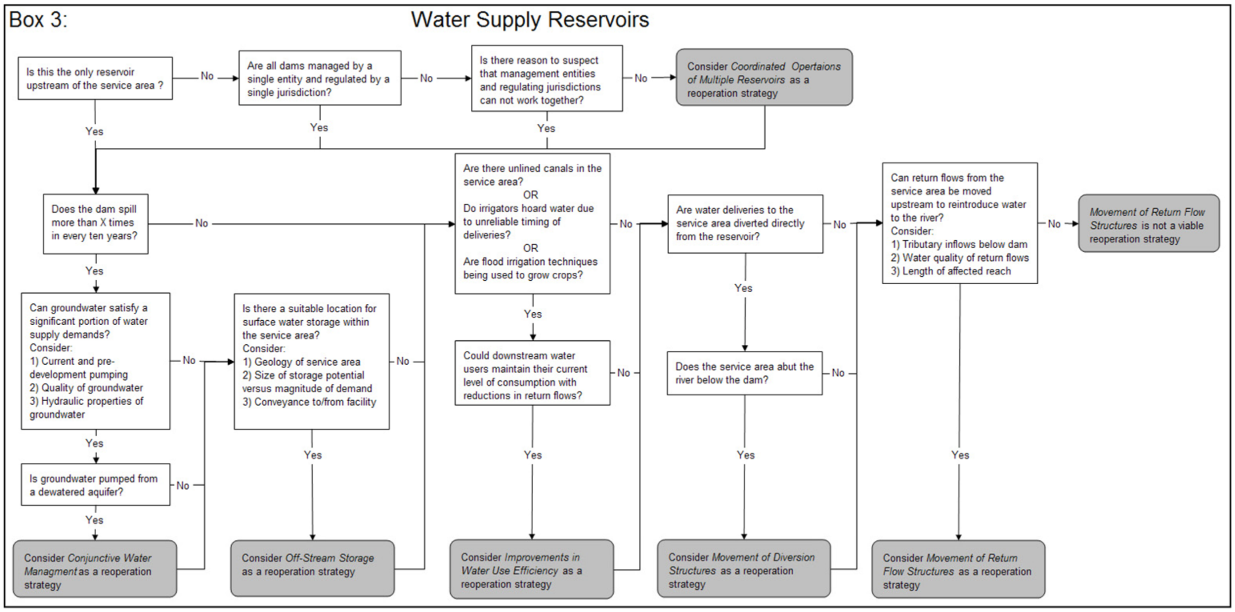
3) *Historical timeseries data of operations*
- Reservoir inflows
- Reservoir releases
- Actual hydropower generation
- Spills
- Changes in storage
- Evaporative losses

4) *Characterization of the service area demands and infrastructure*
- Connectedness of energy grid
- Timing and magnitude of demands (consumptive and power usage)
- Conveyance to/from service areas
- Spatial distribution of demands
- Cropping patterns
- Groundwater pumping
- Flood risk tolerance/exposure

5) *Institutional arrangements*
- System of water rights
- Legal mandates
- Trans-boundary treaties

6) *Economic considerations*
- Pumping costs
  i. Groundwater pumping
  ii. Lifting water to/from river
- Construction costs
  i. Conveyance/return flow structures
  ii. Storage facilities
  iii. Interconnecting energy grids
- Revenue losses due to
  i. Reduced hydropower generation
  ii. Increased groundwater pumping
- Technology investments
  i. Canal lining
  ii. Irrigation equipment
- Purchases
  i. Conservation easements
  ii. Water rights


Box 2:
Screening for Floodplain Restoration Potential
Data Requirements: Local knowledge or pre-development flow records
Required flow for floodplain objective
Data Requirements: Dam/reservoir specification data
Does the reservoir have adequate storage and spillway capacity to release flows of sufficient size to satisfy the restoration objective?
No
Eliminate reservoir from further consideration
Yes
Data Requirements: Basin map
From the river terminus, is this the first dam encountered?
No
Do all downstream dams have sufficient spillway capacity to safely pass flood releases?
No
Eliminate reservoir from further consideration
Yes
Are all dams managed by a single entity and regulated by a single jurisdiction?
No
Is it plausible to assume that management entities and regulating jurisdictions can work together?
No
Eliminate reservoir from further consideration
Yes
Yes
Yes
Data Requirements: Floodplain map & Local knowledge
Is there sufficient capacity within the floodplain to accommodate the required flow for the floodplain objective? Consider:
1) Does the river channel support floodplain inundation?
2) Is urban encroachment limited to the margins of the floodplain, such that it does not interfere with controlled releases for floodplain inundation?
3) Is the floodplain absent of immutable structures that prevent controlled releases for floodplain inundation?
4) Is it plausible to assume that farming communities could be compensated for occasional inundation of agricultural lands?
No
Eliminate reservoir from further consideration
Yes
Data Requirements: Dam/reservoir specification data
What is the operational purpose of the reservoir? (For multi-purpose reservoirs, consider each applicable path separately)
Water Supply
Hydropower
Flood Control
Go to Box 3
Go to Box 4
Go to Box 5


Box 3:
Water Supply Reservoirs
Is this the only reservoir upstream of the service area ?
No
Are all dams managed by a single entity and regulated by a single jurisdiction?
No
Is there reason to suspect that management entities and regulating jurisdictions can not work together?
No
Consider Coordinated Opertaions of Multiple Reservoirs as a reoperation strategy
Yes
Yes
Yes
Does the dam spill more than X times in every ten years?
No
Are there unlined canals in the service area? OR Do irrigators hoard water due to unreliable timing of deliveries? OR Are flood irrigation techniques being used to grow crops?
No
Are water deliveries to the service area diverted directly from the reservoir?
No
Can return flows from the service area be moved upstream to reintroduce water to the river? Consider: 1) Tributary inflows below dam 2) Water quality of return flows 3) Length of affected reach
No
Movement of Return Flow Structures is not a viable reoperation strategy
Yes
Can groundwater satisfy a significant portion of water supply demands? Consider: 1) Current and pre-development pumping 2) Quality of groundwater 3) Hydraulic properties of groundwater
No
Is there a suitable location for surface water storage within the service area? Consider: 1) Geology of service area 2) Size of storage potential versus magnitude of demand 3) Conveyance to/from facility
No
Yes
Could downstream water users maintain their current level of consumption with reductions in return flows?
No
Yes
Does the service area abut the river below the dam?
No
Yes
Is groundwater pumped from a dewatered aquifer?
No
Yes
Yes
Yes
Yes
Yes
Consider Conjunctive Water Managment as a reoperation strategy
Consider Off-Stream Storage as a reoperation strategy
Consider Improvements in Water Use Efficiency as a reoperation strategy
Consider Movement of Diversion Structures as a reoperation strategy
Consider Movement of Return Flow Structures as a reoperation strategy