RAPID EVALUATION TOOL FOR SCREENING THE POTENTIAL FOR REOPTIMIZING HYDROPOWER SYSTEMS

Adapted from Thomas, G. and DiFrancesco, K., 2009. Rapid Evaluation of the Potential for Reoptimizing Hydropower Systems in Africa. Final Report to The World Bank, Washington, DC.

As part of the ***Global Dam Reoperation Initiative,*** the Natural Heritage Institute (NHI) developed a "Rapid Evaluation Tool for Screening the Potential for Reoptimizing Hydropower Systems" (REOPS) to quickly and efficiently screen a large number of dams to identify those that are the most promising candidates for beneficial reoptimization. By reoperation, or reoptimization, we mean the implementation of environmental flows designed to restore downstream ecosystem functions and services (e.g., floodplain livelihoods, food production systems), without significantly decreasing power production.

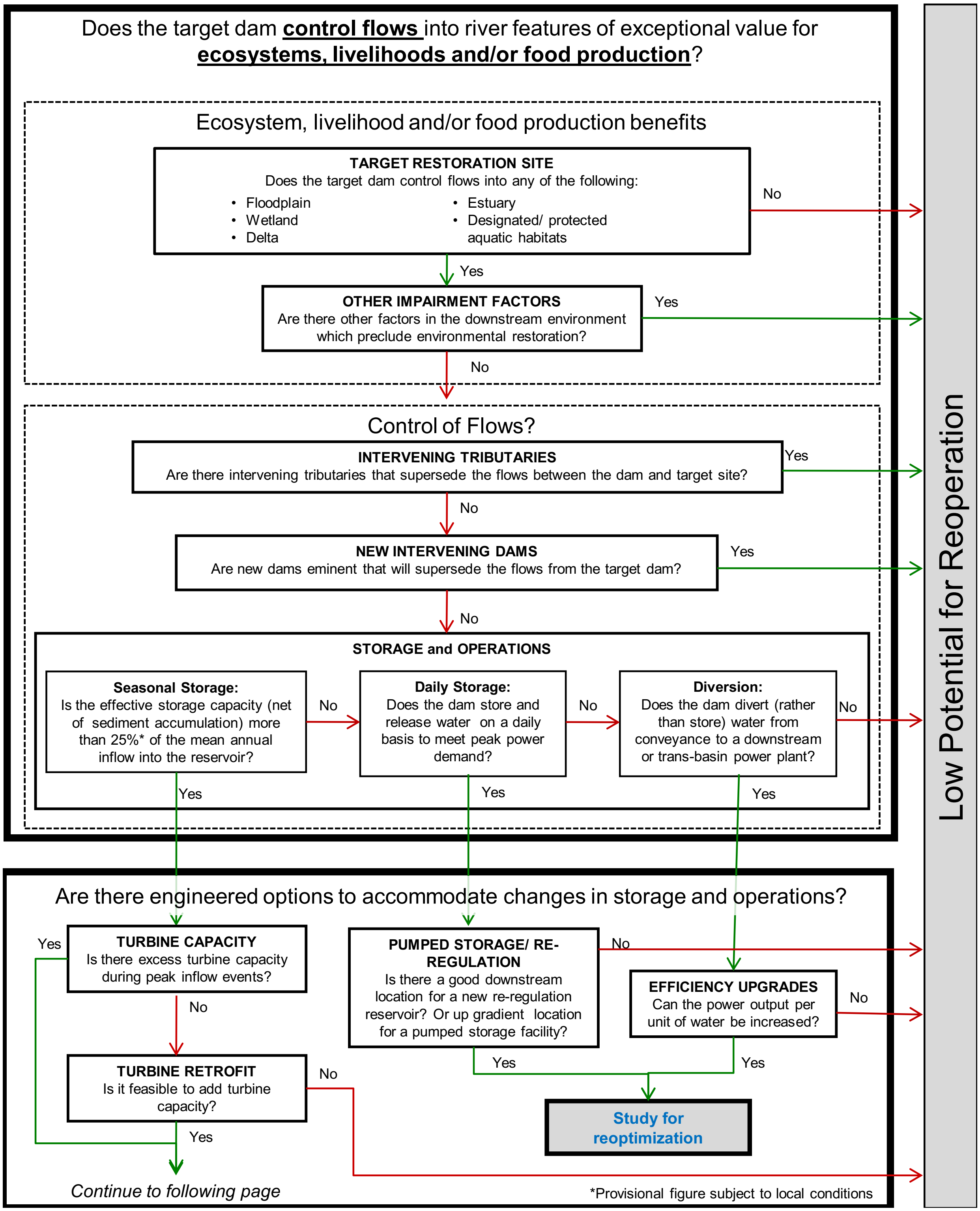
In a world in which there are some 12,000 large hydropower facilities currently operating, the REOPS enables the user to determine where to invest limited financial resources to conduct technical feasibility studies leading to the development of an implementable reoptimization plan for hydropower dams. The tool is designed to be used by individuals with varying levels of training and expertise, ranging from local community leaders and NGOs to project operators, development assistance officials, national planning agency officials or other experts. It requires only information that is fairly readily available from the open literature or from site inspection, and does not require detailed technical assessments. As a rapid assessment tool, it intentionally oversimplifies the subtleties and complexities of the many physical requisites for successful reoperation. Thus, it necessarily misses some opportunities (false negatives) and selects in favor of some dams that will prove to be infeasible on closer inspection. In sum, it sacrifices some precision for greater speed and efficiency.

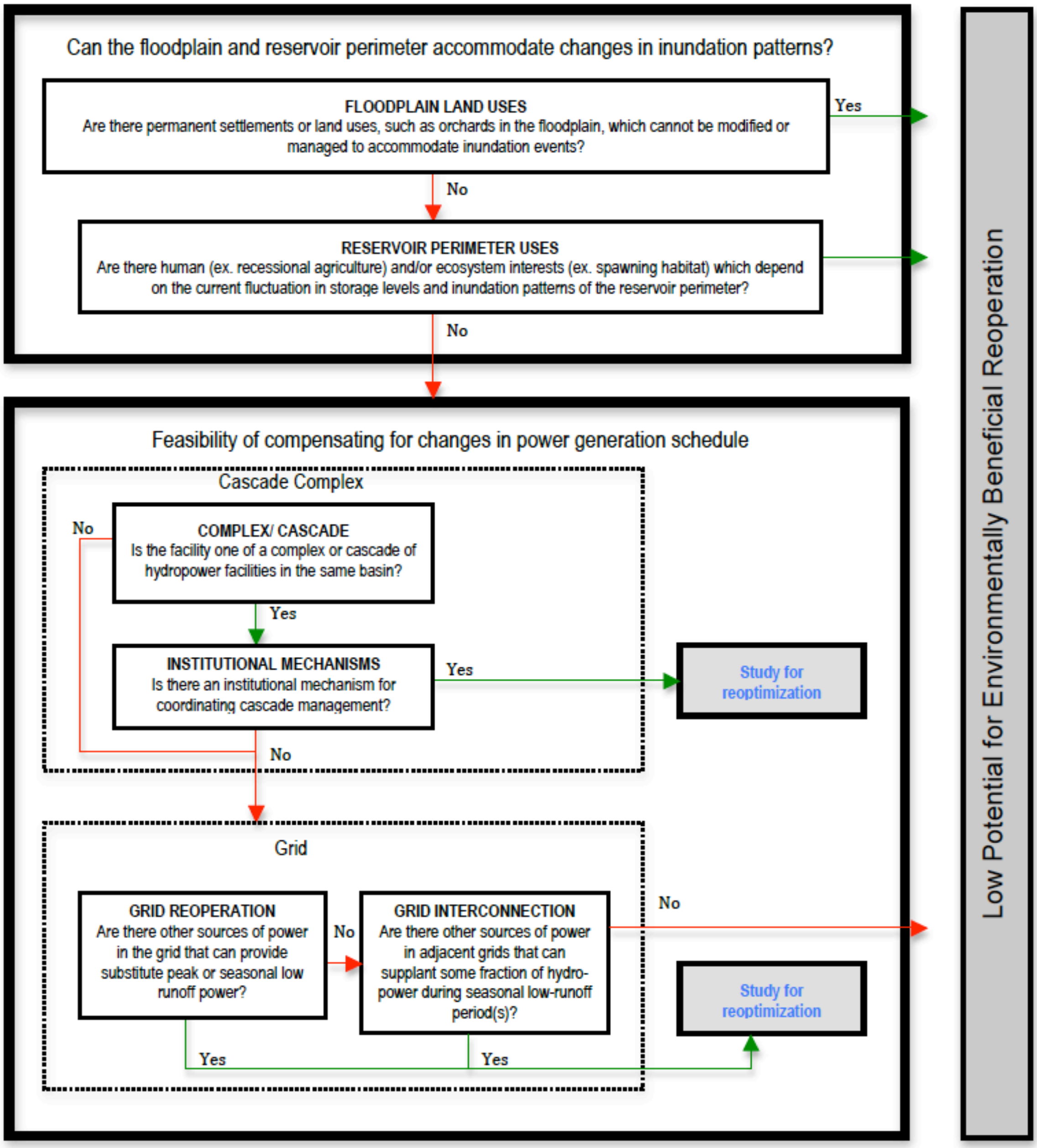
REOPS is a "dichotomous key", in which one proceeds through a logic pathway by answering a series of queries in either the affirmative or negative. Depending on the answer, one will either default out of the pathway, with the conclusion that the dam is not a good candidate for reoptimization, or will be directed to a succeeding cell. The cells themselves are organized around four major considerations: (1) whether the dam controls flows into downstream river features of exceptional biological productivity; (2) whether the land uses in the river basin, downstream and upstream of the dam, are amenable to reoperation; (3) whether the powerhouse itself is or can be made suitable for reoperation; and (4) whether any of three types of techniques for accommodating changes in the schedule for power generation are feasible. Thus, there are two converging lines of inquiry, one concerning the physical characteristics of the affected river basin, and one concerning the physical characteristics of the dam, reservoir and powerhouse.

It is also important to note that REOPS assesses only the physical requisites for successful reoptimization of hydropower dams. Facilities that survive this technical analysis must then also be subjected to an economic feasibility analysis that will weigh the costs and benefits of reoptimization to see where the break-even point may lie. That will often determine whether, and to what extent, reoperation is economically justified.

The subsequent pages display the REOPS schematic, followed by an explanation and guidance in the use of the tool, cell by cell.

Rapid Evaluation Tool for Screening the Potential for Reoptimizing Hydropower Systems




Can the floodplain and reservoir perimeter accommodate changes in inundation patterns?
FLOODPLAIN LAND USES
Are there permanent settlements or land uses, such as orchards in the floodplain, which cannot be modified or managed to accommodate inundation events?
Yes
No
RESERVOIR PERIMETER USES
Are there human (ex. recessional agriculture) and/or ecosystem interests (ex. spawning habitat) which depend on the current fluctuation in storage levels and inundation patterns of the reservoir perimeter?
No
Feasibility of compensating for changes in power generation schedule
Cascade Complex
No
COMPLEX/ CASCADE
Is the facility one of a complex or cascade of hydropower facilities in the same basin?
Yes
INSTITUTIONAL MECHANISMS
Is there an institutional mechanism for coordinating cascade management?
Yes
Study for reoptimization
No
Grid
GRID REOPERATION
Are there other sources of power in the grid that can provide substitute peak or seasonal low runoff power?
No
GRID INTERCONNECTION
Are there other sources of power in adjacent grids that can supplant some fraction of hydro-power during seasonal low-runoff period(s)?
No
Study for reoptimization
Yes
Yes
Low Potential for Environmentally Beneficial Reoperation

Does the Target Dam Control Flows into River Features of Exceptional Value for Ecosystems, Livelihoods and/or Food Production?

Ecosystem, livelihood and/or food production benefits:

Target restoration site:

Reoperation of existing dams to produce a more variable flow pattern that mimics natural conditions will only be worthwhile if that produces tangible improvements in the productivity of the downstream river system. The types of benefits of interest include both improvements in aquatic habitats and ecosystem functions, including morphological benefits, and improvements in river-dependent livelihoods and food productions systems, such as recessional cultivation, grazing, and fishing. The precise flow characteristics needed for these benefits—expressed in terms of magnitudes, duration, frequency and timing of flows—can only be ascertained through an environmental flow assessment, which is time and resource intensive and therefore appropriate as a result of, not a prerequisite to, a screening analysis. And, productivity benefits are a matter of degree.

Thus, a reliable and readily ascertainable proxy is needed to indicate whether a downstream river reach is likely to benefit from dam reoperation. In general, there are four types of river features that are particularly productive, both ecologically and in terms of human uses. These are: (1) broad, alluvial floodplains, (2) wetlands systems that are, or formerly were, seasonally connected to the river, (3) inland deltas, and (4) estuaries. By contrast, river canyons and gorges are less likely to yield large flow restoration benefits, unless they harbor species of special conservation value.

These types of river features are readily identifiable by looking at maps, utilizing remote imagery such as Landsat images or Google Earth, or learning where the dam is located relative to designated protected areas in the basin, such as Ramsar sites, World Heritage Sites, Important Bird Areas, designated habitat for endangered species, wildlife refuges, national parks, or other protected areas. If no such downstream features are found, the dam is probably not a strong candidate for reoperation. Depending on the number and size of intervening tributaries, these features may be affected by flow regulation if they occur within a few hundred kilometers of the target dam.

Other Impairment Factors:

Even if such river features are found, there are circumstances where the habitat values or human livelihood values are so compromised by other factors that flow restoration will not do much good. Examples may include mining operations in the river or riverbank, wastewater contamination from agriculture of urban runoff, overharvesting of fish, and massive sedimentation from deforestation or other erosive land uses. In such cases, again, it will not be worthwhile to improve the flow regime.[1]

[1] *Information sources for target restoration site and other impairment factors:*

Bernacsek, G.M., 1984. Guidelines for dam design and operation to optimize fish production in impounded river basins (based on a review of the ecological effects of large dams in Africa). CIFA Tech. Pap., (11):98. Available from: <http://www.fao.org/docrep/005/AC675E/AC675E00.htm> (accessed Oct. 2008).

Birdlife International. Important Bird Areas. Datazone. Available from: <http://www.birdlife.org/datazone/index.html> (accessed Oct. 2008).

IUCN, 2008. Red List of Threatened Species. Available from: <http://www.iucnredlist.org/> (accessed March 2009).

Controlling Flows:

Where the desired riverine features are found, the next inquiry is whether the target dam actually *controls* the flows through those river reaches; that is to say, does the operation of the dam actually have a substantial impact on the magnitude, duration, frequency and timing of the flow patterns? The following four considerations must be taken into account.

Intervening Tributaries:

If there are other streams flowing into the river between the target dam and the river feature of concern, and if these provide substantial new flows, the effect of the target dam may be superseded. This will depend on the relative volume of flows contributed by these intervening tributaries, and whether they themselves are controlled by dams. In some cases, where the tributaries are not controlled, they may actually enhance the reoperation potential of the target dam because a relatively small additional season release from the target dam may be enough to produce a controlled seasonal flood event in the downstream river feature of interest. So this consideration factor can cut both ways.[2]

New Intervening Dams:

Not infrequently, large new dams are being planned or are under construction in the river reach between the target dam and the river feature of interest for restoration. If it is a large dam, it is probable that the effect of that new dam will supersede the effects from the target dam. In that event, funding would be better spent on evaluating options for improving the siting, design or operation of the new dam.[3]

Knaap, M. van der., 1994. Status of fish stocks and fisheries of thirteen medium-sized African reservoirs. CIFA Technical Paper. No. 26. FAO, Rome.

Shahin, Mamdouh., 2002. Hydrology and water resources of Africa. Dordrecht; Boston: Kluwer Academic.

Thieme, Michele L., 2005. Freshwater Ecoregions of Africa and Madagascar: A Conservation Assessment. Covelo, CA, USA: Island Press. Information. Available online at: http://www.feow.org/.

Vanden Bossche, J.P. & Bernacsek, G.M., 1990-1991. Source book for the inland fishery resources of Africa. Vols. 1-3. CIFA Technical Papers Nos. 18/1, 18/2,18/3. FAO, Rome.

Wetlands International, 2008. Ramsar Site Database. Available from: <http://ramsar.wetlands.org/ (accessed Oct. 2008).

World Database on Protected Areas. Available from: <http://www.wdpa.org/ (accessed Oct. 2008).

[2] *Information sources for intervening tributaries:*

University of New Hampshire - Water Systems Analysis Group. Available from: <http://www.wsag.unh.edu/data.html> (accessed Oct. 2008).

USGS. Hydro 1k Africa dataset. Available from: <http://eros.usgs.gov/products/elevation/gtopo30/hydro/africa.html> (accessed Oct. 2008).

[3] *Information sources for new intervening dams:*

Africa Energy Intelligence. Available from: <http://www.africaintelligence.com> (accessed Oct. 2008).

Southern African Development Community (SADC). Status of the generation projects in the Southern African Power Pool. Available from: <http://www.sardc.net/Editorial/sadctoday/view.asp?vol=587&pubno=v10n4> (accessed Oct. 2008).

Can the Floodplain and Reservoir Perimeter Accommodate Changes in Inundation Patterns?

Floodplain Land Uses:

The issue here is whether the downstream river channel can accommodate larger magnitudes of flow—shaped to create beneficial inundation patterns—compared to current conditions. This is an issue because flow regulation by dams attracts settlement in the former floodplain. If the post-dam settlement pattern is such that reintroduction of controlled flood events would create large risks to life and property, that may preclude reoperation of the dam.

The important consideration here is that the post-dam land uses in the floodplain may or may not be immutable. In general, we can say that permanent habitations on a large scale, as in the case of riverbank towns or cities, may create such a pinch point, unless it is feasible to wall them off from the river with berms or levees. By contrast, less intensive structural development, or structures that are movable or of low economic value, may be moved somewhat higher up in the floodplain to accommodate a controlled flood event. Indeed, a more productive floodplain may be incentive enough to induce these changes voluntarily.

Agricultural uses of the floodplain may present a mixed situation. Grazing or annual cropping is inherently malleable. Seasonal inundation may be quite beneficial to these land uses and easily accommodated. If permanent crops have been planted in the floodplain, such as orchards with high capital investments, the accommodation may be more problematic or precluded. Government land use laws and policies may come into play here. For instance, in some countries, the national government retains overriding ownership rights in floodplains, allowing them to require settlers to vacate in the event the former flow regime is re-established.

Reservoir Perimeter Uses:

Reoperation of reservoirs will also affect land uses on its perimeter. In general, moving hydropower operations in the direction of run-of-the-river will tend to stabilize reservoir levels toward the high end of the range. That will eliminate lakeside land uses that may have arisen since the dam was built, and will also reduce the seasonal change in lake levels that can be important for recessional agriculture and spawning and rearing of some fish species. While these are artificial uses, they may have importance to the local economy. An example is Lake Tana in Ethiopia. Again, where these uses must be preserved, reoperation may be precluded or limited.[4]

Are There Engineered Options to Accommodate Changes in Storage and Operations?

Storage and Operations:

A dam can only be said to control flows if it distorts the pattern of inflows into the reservoir. Hydropower dams that release water into the downstream channel in rough proportion to the reservoir inflow are called "run of the river" dams. These are not good prospects for a reoperation study simply because they are already operated in a manner that is compatible with natural flows. Although these

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[4] *Information sources for floodplain and reservoir perimeter land use:*

Thieme, Michele L., 2005. Freshwater Ecoregions of Africa and Madagascar: A Conservation Assessment. Covelo, CA, USA: Island Press. Information available online at: http://www.feow.org/.

dams may still damage fisheries and ecosystems, by blocking fish passage and disrupting sediment flows, for instance, these impacts are outside of the scope of this project, which focuses on the water management aspect of rehabilitation. We can eliminate these dams from further consideration.

For other dams, however, there are three modes of operating dams that make them potential candidates for reoperation. These are considered below:

<u>Seasonal storage:</u>

Seasonal storage dams store water during the wet season(s) and release that water during the dry season(s). They may also store water from relatively wet years for use in relatively dry years. In doing so, they necessarily distort the natural hydrograph, in effect reducing flows in the downstream channel during the wet season(s) and increasing flows during the dry season(s). As a result, the natural variability in flows is lost and the river features of interest are deprived of both the seasonal flooding and the low flows that drive their productivity. For these dams, reoperation will entail moving their storage and release patterns more in the direction of run-of-the-river operations, where the dam is used primarily to create (and maximize) the hydraulic head needed to generate power.

"Storage" is a relative term, however, and there are two important considerations that bear upon it. The first is that many dams progressively lose their effective storage capacity as a result of sediment accumulation. Particularly in settings where the upstream catchment erodes large quantities of sediment during peak runoff events, due to deforestation and intensive cultivation, the life of the reservoir may be measured in a few decades. Unless the reservoir is dredged (often quite expensive) and the erosive land uses remediated (very difficult because of the large numbers of land users), the reservoir will become increasingly like a run-of-the -river project and less and less a good prospect for a reoperation study. Dams with a short remaining lifespan are not worth the effort to reoperate.

The second consideration is the percentage of annual inflow that the dam is capable of storing. This can vary over a wide range. Some very large dams can store several years of inflow. Others may store only a small fraction of the annual inflow. Even very large dams may fit in this latter category due to the very high volume of flow in the river. The Three Gorges Project, for instance, can store only about 11% of the mean annual flow of the Yangtze River in China. Does this make it a "run-of-the-river" project that cannot be significantly reoperated? Not necessarily. But the reoperational flexibility will clearly depend on these inflow/storage ratios. It is therefore difficult to identify a threshold criterion. In most cases, however, a dam that can store less than 25% of the annual runoff will probably not be a good candidate.

<u>Daily storage:</u>

Some dams store and release water on a daily cycle to follow the electricity demand curve as it changes throughout the day. These are called "peak power" facilities. They generate power only during the hours of the day of maximum power demand for that grid system, and will sharply reduce or eliminate releases for the other hours of the day. This creates a sharp spike in the hydrograph, which can be particularly devastating to the downstream river uses. Unless these dams can be converted to a "base load" role in the power generation system, the only option for ameliorating their destructive downstream flow pattern is to construct a pumped storage or re-regulation facility, which is described below.

Diversion:

Some hydropower dams are actually just diversion barrages. These have very limited storage capacity. Their function is to divert water into a canal or pipeline to convey it by gravity (but without appreciable loss of elevation) to a downstream or transbasin powerhouse, where it is released through penstocks to create the necessary hydraulic head. In these projects, the river reach that suffers the greatest impacts is the intervening reach, which may be partially or entirely dewatered, at least during the dry season. Where the water re-enters the same river downstream, that intervening reach may not be lengthy and will probably be located in a river canyon with relatively steep gradients. The ecosystem and food production values in this reach may not be exceptionally high (on the other hand, if the diversion dam project survives the REOPS dichotomous pathway to this cell, it is because those river resource values are judged to be important). Where the project operates in a transbasin mode, the dewatering may persist for a much longer reach, and the receiving basin may also suffer a major flow alteration.

Turbine capacity:

Reverting back to the seasonal storage facilities (which represent the most practical and likely candidates for reoperation), the next consideration is whether the power plant can accommodate increases in power generation during the wet season, so that reservoir operations that move in the direction of run-of-the-river will not forego power generation. In sum, we want to be sure that the higher seasonal releases needed to generate a controlled flood event downstream do not by-pass the turbines. If they do that, the reoperation amounts to a reallocation of benefits, not a reoptimization of benefits. Whether this is possible depends on whether there is unused turbine capacity during the wet season, under current operations. If so, that can be utilized to improve the release pattern. If not, we move to the next cell.

Turbine Retrofit:

This cell asks the question whether it is feasible—technically and economically—to install additional turbines in this hydropower facility such that additional water releases can be made through these turbines in synchrony with the peak runoff events. There are three possibilities: (1) if the outlets from the dam allow more water to be released than the capacity of the existing turbines, it may be possible to add another turbine to the powerhouse; (2) if there is a flood spillway or tunnel that can be retrofit with one or more turbines, that is a second option; (3), if neither of these are possible, we must ask whether it is possible to add additional outlets to the dam.

In the event that we cannot make better use of existing turbines, or add additional ones, the target dam will not be a good candidate for a reoptimization study.

Pumped storage/reregulation:

For daily peaking facilities, there are two engineered strategies for ameliorating the adverse effects on downstream flow patterns. One is to construct a pumped storage facility. Under this approach, the target dam would be reoperated to generate a fairly uniform release pattern during the course of the day. Note, that still does not re-establish the seasonal variability that is desired for ecosystem restoration, but it does eliminate the sharp changes in diurnal flows. During the times of non-peak demand each day, this power would be used to pump water out of the reservoir into an upstream (probably off-river) storage facility. Then during the hours of peak demand, this water would be released back into the target reservoir through power turbines. There is a net power generation penalty associated with this mode of operating and, again, it will be a rare circumstance where a power company is willing to incur both the capital costs and the power generation losses to implement this strategy for the benefit of downstream ecosystems and riverine communities.

Efficiency Upgrades:

The challenge in developing a reoperation strategy for diversion-type power facilities is that releases of water into the downstream channel come at the expense of water released to the powerhouse, and thus result in a reduction in power output. This is contrary to the "reoptimization" objective, which is to reoperate to improve environmental performance without power generation penalties.

The option that can work is to upgrade the efficiency of the turbines in the powerhouse such that the baseline power output can be maintained with less water throughput. In many cases in Africa, the power plants are old, with deferred maintenance, and the potential for efficiency upgrades is quite substantial.

Whether this reoperation strategy will be acceptable is more problematic. Interviews with power officials uniformly revealed that they would not be willing to invest in efficiency upgrades and then forego the resulting increases in power generation in order to create non-power benefits such as improved ecosystems and food production. Thus, we conclude, that it will be a rare circumstance where the environmental benefits are large enough and the power penalties small enough to make these dams attractive candidates for reoperation.

Feasibility of Compensating for Changes in Power Generation Schedule

Changing reservoir operations from a storage modality in the direction of a run-of-the-river modality necessarily entails changing the scheduling of power generation. Under a reoptimization approach, it does not entail reducing the total power output, however. Indeed, in many cases, reoptimization may actually increase annual power output quite substantially by increasing the average storage levels and, consequently, the hydraulic head.

The reoperation will result in more power being produced during the rainy season(s) and less power being produced during the dry season(s), compared to current operations. That will adversely affect the power system reliability, unless compensating changes are made by other power generators in the system. There are three possible ways in which the change in scheduling can be accommodated at the level of (1) a complex or cascade of dams with coordinated operations, (2) individual dam sites, where there is the opportunity to upgrade the efficiency of the powerhouse, and (3) the electrical grid, where other generators can compensate for the change in power scheduling from the target hydropower dam.

1) Complex/Cascade:

Where the target power dam controls the flows into the river features of interest, and is part of a complex of dams on several tributaries or a cascade of dams on the same river, it may be possible to offset the change in power output at the target dam by also reoperating the other dams in a compensatory manner. Essentially, one or more of the non target dams would be required to also change its power generation schedule to produce more power during the dry season and less power during the rainy season(s) than under current conditions. That will create even larger flow distortions downstream of these compensating dams than occurs today. If the environmental assets below the target dam are of exceptional value, however, the net effect on river productivity should be positive.

Determining whether it is feasible to reoperate an entire cascade or complex in this manner will often require creating a mass balance hydrologic tracking model to test various reoperation scenarios. This is not a difficult challenge in most circumstances, but will require a tool that goes beyond REOP. A simple spread sheet tool is usually adequate for a screening or reconnaissance level of analysis.[5]

Institutional Mechanisms:

Obviously, such coordinated, multi-reservoir, reoperation is much easier to accomplish in cases where all of the dams feed into to the same electrical grid and are operated by the same entity. Where those conditions do not exist, compensatory reoperation by hydropower dams may not be feasible.

2) Site Level:

Efficiency Upgrades:

At an individual hydropower dam, it may still be possible to partially neutralize the effects of rescheduling the power output through efficiency upgrades. If the turbines can generate the same amount of power with less water throughput, this may allow the same amount of power to be generated during the dry season while emulating the lower flow events in a more natural seasonal flow pattern.

Power Variability

However, the change in operations will then result in an even larger increase in power generation during the wet season(s). This is beneficial from the standpoint of total power output, but also creates an even larger differential between dry and wet season power reliability. Since dry season reliability problems are already a large management issue for African power companies, this reoperation option may not be acceptable to them.

3) Grid Level:

Grid Reoperation:

Rescheduling of power output at a target dam can be accommodated by changing the role this power generator plays in the mix of generating facilities in an electrical distribution system. Again, the total power output will not be diminished, and may actually increase. However, by reducing the amount of power generated during the dry season(s), other power plants, such as oil or gas turbines, will need to make up the difference. This may entail capital expenditures to increase the capacity of these thermal power plants. During the wet season(s), the opposite would happen: power output from the target hydropower dam would increase over current conditions, and some of the thermal plants would be idled.

This compensatory scenario is not problematic from a technical standpoint (addition thermal capacity to the grid is usually warranted in the power-deficient African electrical grids in any event. Rather the feasibility issue goes to the economics of adding generating capacity (and possibly transmission capacity and turbine capacity) that will operate with a relatively low capacity factor on

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[5] *Information sources for cascade/complex:* UN - FAO. AquaStat. Geo-referenced database on African dams. Available from: <http://www.fao.org/nr/water/AquaStat /damsafrica/index.stm> (accessed Oct. 2008).

an annual basis. The operating (fuel) costs associated with these thermal additions should not increase, however. Whether these increased capital costs can be justified depends on the cost-benefit analysis, described in the introductory paragraphs, which goes beyond what the REOPS tool is designed to provide. However, in many cases, it appears that the benefits of hydropower dam reoperation will be large enough to warrant such capital investments.

Grid Interconnection:

The smaller the contribution of the target power dam to the total power supply in the grid system, the easier it will be to accommodate the rescheduling of output. Where the existing electrical grid system does not have sufficient diversity and capacity of power generators to be able to compensate for the change in the role of the target hydropower dam, it may still be possible to contemplate interconnecting with a neighboring grid to provide the requisite conditions. In the current era when grid interconnections are being studied and pursued pervasively in Africa, Asia and Latin America, this scenario will often be quite worthy of consideration. The analysis proceeds just as in the preceding explanation, except that the number of power generation units available to help accommodate the rescheduling of the target dam may be considerably larger.[6]

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[6] *Information sources for grid reoperation or interconnection*:

Energy Information Administration. Country profiles. Available from: <http://www.eia.doe.gov/> (accessed Oct. 2008).

Global Energy Network Institution. National Energy Grid Map. Available from: <http://www.geni.org/globalenergy/library/national_energy_grid/index.shtml> (accessed Oct. 2008).

International Energy Agency. Country profiles. Available from: <http://www.iea.org> (accessed Oct. 2008).

Mbendi Information Service. Country electricity sector profiles. Available from: <http://www.mbendi.co.za/> (accessed Oct. 2008).