Water Papers

REHABILITATION OF HYDROPOWER
-An introduction to economic and technical issues

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ACRONYMS AND ABBREVIATIONS

AFR	Africa Region (Constitutes Sub-Saharan Africa)
HAT	Hydropower Assessment Tool for rapid assessment of the potential for rehab
LCR	Latin America and Caribbean Region
MENA	Middle East and North Africa Region

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EXECUTIVE SUMMARY

1. **Size of the hydroelectric plant rehabilitation market**. The market for hydroelectric plant rehabilitation (abstracting from major civil works modifications to headworks to alter river flows) is large in developing countries, both absolutely and even more significantly, proportionally to total power generation and energy production. Part of this study was devoted to development of a coarse screening tool device (the hydropower assessment tool) which, applied to a proprietary data base, results in inventories of existing plants in two regions of the world - continental Africa and Central America and Mexico. These plants sum to a total capacity of over 22,000 MW in Africa and 15,000 MW in Central America and Mexico assets which if they had to be replaced today would require US$ 50 - 100 billion in Greenfield costs, and of course years of planning and construction. Of those totals, 8500 MW in Africa and nearly 3800 MW in Central America[1] are over 35 years old, not old for the headworks which house and serve the generating plants themselves, but approaching replacement age for various electro-mechanical assemblies in the plants. Within the next decade, these aggregate plant capacities will roughly double to 16,500 MW in Africa and 8600 MW in Central America. This then, for only two regions of the developing world, is the large and important market for hydroelectric plant rehabilitation.

2. **Scenarios of choice and scenarios of necessity**. In developed countries and more fortunate developing countries, there is always some redundancy in energy sources which permit well-planned maintenance programs for hydroelectric plants, and replacement of parts and entire assemblies on a fairly routine basis. The funding for such measures is also needed, either by publicly regulated private utility businesses, or government entities of various types. Much of the discussion of this report concerns the technical, cost, and benefit factors which impact decisions on when larger investments, such as those involving full-scale rehabilitation or replacement of major equipment, should be made, what types of rehabilitation might be implemented, how much this might cost, what problems might arise, and what benefits might be achieved. These are all scenarios of choice. If, however, no investment action is taken, the scenario becomes one of necessity. Eventually plant deterioration will pass the stages of efficiency loss and occasional breakdown and outages, and approach total collapse, where the entire value of the plant, the headworks itself is not only at stake, but represents an increasing safety risk. Such factors as a shortage of funds, perceived impossibility of shedding load to permit opportunities for rehabilitation, political myopia or conflict, among others, can pose serious challenges. Many of the plants in this data base are over 70 years old, quite a few over 90. Anecdotally, many are in extremely poor condition, yet still absolutely necessary to their generation systems. One lesson of this exercise is to include hydro plants in rationally planned rehabilitation cycles before the period of choice ends, and that of emergency rehabilitation begins. To do otherwise is simply to waste the existing assets.

3. **Greenfield projects versus rehabilitation**. Though often couched in oppositional terms, there is no real dichotomy between true Greenfield hydroelectric projects and hydroelectric rehabilitation operations in terms of providing renewable energy to power systems. When major

[1] In the remainder of the document, references to Central America include Costa Rica, Nicaragua, Panama, Honduras, and El Salvador, as well as Mexico.

new sources of renewable energy are needed in areas where good dam or run-of-river sites are available, Greenfield developments of various configurations must be considered. Rehabilitation is first about retaining and preserving what is already functioning, and then about possible incremental increases in capacity at existing sites, hopefully at reasonable cost and with minimal delay. The line be between the two may become blurred where major civil works modifications - including new tunnels, penstocks, bays for additional turbines and generators are built into existing headworks to permit major capacity additions. As such investments imply large changes in the handling of river flows, and thus to partake of the main character of site specific, Greenfield hydroelectric projects, they are not covered in detail in this report. Indeed, the lack of such major impacts on the natural environment (and by extension on the social environment) should be, and typically is, a major "advantage" of rehabilitation projects, in terms of preserving nature and saving time. On the other hand, the very complexities of Greenfield projects may rightly be seen as opportunities to create large public goods, like removing catastrophic peaks of floods, preserving environmental flows, and making rivers navigable, in addition to providing power and water for the dry season - goods far beyond the financing and implementation of rehabilitation projects.

4. **Complications of rehabilitation.** Despite the above, many rehabilitation projects do not proceed as simply, cheaply, or quickly as planned. Perhaps the largest problem is that mentioned above - extracting the working units from their constant generation program, first to possibly dismantle the units to make an accurate detailed assessment of the condition of each unit to determine the true costs and time of rewinding or replacement. Then, suppliers and consumers must prepare for the temporary outage. When this is compounded by increases in cost estimates when dismantling and detailed analysis finally does occur, political factors often enter to further delay and complicate project schedules. In some cases, this has actually forced years of waiting, e.g., for new thermal capacity to actually be installed in the system to permit this hydro outage. More common would be the stretching of the rehabiliation schedule to permit unit-by-unit rehabilitation. Then there are often debates within governments on the issue of like-for-like replacement of parts and assemblies, versus upgrades into more modern equipment. The former may not owe its force simply to institutional inertia - comfort with known equipment and processes. As a very mature technology, only very old hydroelectric equipment has very strong design efficiency handicaps (perhaps only 5-15%) against the most modern. By far the largest boost to performance (perhaps up to 30%) from rehabilitation will derive from the replacement of deteriorated equipment by new or rebuilt equipment, and this can be achieved with more traditional designs. New designs for major assemblies will require reviewing designs for all connected modules in the plant, to ensure that interrelated processes continue to work smoothly, and for agencies depleted of skilled engineers, or even of funds or time, this may argue for safety of like-for-like replacement - if the old equipment is still available. Finally, many rehabilitation projects do not escape the major safeguard (impact) issues of the past at all, but inherit as legacies the ignored environmental and social (especially resettlement) issues ignored by the original Greenfield projects planned and/or implemented 30 or 50 years before. And indeed this assessment is often correct, and put into practice. The critical political point which here needs to be made by the relevant political leadership, is that legacy issues are not brought by the rehabilitation project - only their potential solutions - and thus undue delay of the rehabilitation project on such grounds harms the very public goods ostensibly at stake.

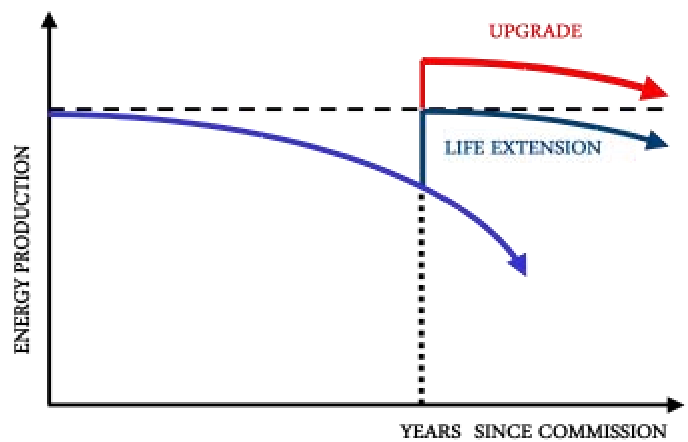
1 CONTEXT FOR THE STUDY

Rising energy prices, climate change and the increased role of water resources for economic growth and poverty alleviation have led to a renewed focus on the role of hydropower. As the largest renewable source of energy available, hydroelectric energy had a new record production in 2010 with than 3400 TWh (equivalent to 780 million tons of oil) produced. A sobering fact is that this is but 6.5% of the annual energy used globally. In this environment, there is a strong need to scale up on hydropower, but at the same time it is necessary optimize the current generation capacity.

The World Bank (the Bank) has established a framework for hydropower investments in recognition of the potential multiple benefits of hydropower, when developed sustainably. The Bank lending portfolio covers three types of projects: a) new storage hydropower projects, b) new small and run-of-river hydropower projects and c) rehabilitation of existing facilities which is the subject of this study report. Rehabilitation in the context of other potential intervention strategies must be defined. The scope of intervention in terms of existing hydropower assets can include:

Rehabilitation - Hydroelectric station rehabilitation covers a broad set of activities, including repairing/replacing components, upgrading generating capability and availability, realigning services to meet market opportunities and new market requirements and modifying the management of water resources to enhance ecosystems. In the current study, rehabilitation is focused on the major electrical and mechanical equipment associated with power generation, namely the turbine and generator. Other components would be included in most rehabilitation projects and would contribute to the overall cost but major civil works changes (with the possible exception of draft tube modifications) are excluded. Rehabilitation can start with the replacement of equipment on a "like for like" basis where there is minimum effort to enhance the overall output of the station. The primary objective of this is to provide **"life extension"** to the existing facilities and restore their initial performances. In contrast it can often be justified to include an **"upgrade"** of the equipment (efficiency, output) which yields greater output but at increased costs which is justified by the additional revenue over the service life of the equipment. This study examines both of these investment scenarios. Non-structural optimization, such as improved operation rules based on improved hydrology, timing of releases in cascades etc has not been considered.

Figure 1.1 The figure illustrates how energy production is lost over time. The Upgrade vs Life extension.



Project Expansion – Hydroelectric generating stations have been known to have service lives of up to 100 years and in some instances even longer. Where the service life is long then it is quite likely that the station may not be developed to its economic potential based on today's energy and capacity values and equipment cost and performance. In such instances an increase in station capacity (Project Expansion) by installing additional generating units can be justified. In most cases significant increases in station capacity will require installation of additional units, which if not foreseen and prepared for in the original design/construction will likely require major civil works. Such cases of project expansion are not covered (except in passing) in this report.

Project Redevelopment – In projects where the residual service life is too short to justify Rehabilitation or Project Expansion, Project Redevelopment can be considered. In this scenario the civil works (potentially a dam and power facilities) is redeveloped with completely new generating equipment. This scenario is not considered in this study since it, in most cases, requires extensive site-specific engineering studies including environmental and sustainability assessments which cannot be treated in a broad based manner as is being done for the current study.

Greenfield Development – Greenfield development is the design and construction of a totally new generating station at a site not currently developed. Noted advantages of rehabilitation schemes compared to Greenfield developments are cost effectiveness, a shorter development and implementation schedule, lower hydrologic, socio-environmental and institutional risks, and decreased financing risk. Potential disadvantages of rehabilitations include unexpected technical problems, unexpected legacy environmental and social issues, unattained performance issues, losses and impacts associated with downtime and potential institutional issues.

The hydroelectric industry has undergone several phases of project development over its roughly 110 years of existence. Up to the 1980's, most of the developments occurred as Greenfield projects. However, with an increasingly strict regulatory environment and with competitive alternative sources of energy supply, the appetite for capital intensive Greenfield hydro projects diminished in the 1980's and 1990's. During this period, emphasis shifted to the improvement and upgrading of existing facilities that had aged significantly and for which substantial modernization and increase in efficiencies and output could be achieved at relatively modest cost.

In addition to direct rehabilitation projects, deregulation and privatization of the industry introduced the need for technical and financial due diligence assessments, often as part of acquisition efforts. These projects usually involve assessment of the potential for upgrading, technical project improvements and enhancement of environmental and socioeconomic benefits.

Significant generation benefits from improved efficiencies and improved/optimized plant operation as well as reductions in operation and maintenance costs, have traditionally provided the economic justification for rehabilitation projects. In most of the developed world, such projects also afford the opportunity to address environmental and socio-economic concerns associated with plant operations and these are usually incorporated in a relicensing process, resulting in sustainable conditions for plant operations.

It is in this backdrop, as well as the recent increases in the costs of new construction, that the increasing value of hydroelectric station rehabilitation, as opposed to Greenfield development is recognized. While advantages of rehabilitation schemes have been identified and realized in developed countries, the practices surrounding rehabilitation schemes in developing countries are not as well documented.

1.1 Regions

The current study examines issues associated with hydroelectric station rehabilitation schemes under study or implemented, with a focus on countries in Africa and Central America including Mexico[2], with the aim of deriving meaningful feedback for future development and investment, based on lessons learned. It also examines the current fleet of generating stations in Continental Africa (AFR plus African countries in the MENA region) including Madagascar and Central America (in LCR region) to identify the rehabilitation potential through screening and preliminary economic analysis subject to the limits of available information.

Figure 1.2 Map of selected regions for study.

1.2 Climate Change and Changing Hydrology

Water is the fuel of hydropower, and changing hydrology has always been an issue for the industry. Climate change is making future hydrology harder to predict, with potentially more severe impacts on annual quantity and availability as well as increased risk of floods and droughts.

As an adaptation measure to increased variability, one might consider increasing the storage capacity of a given hydropower scheme during a rehabilitation project. More intense storms might dictate larger spillways and gates, which could also improve management of the watershed. Increasing flows of debris and sediments are other factors that can damage or block necessary infrastructure. Investing in improved hydrological data collection and analysis, robust engineering that improves safety and reliability and operational changes that allows for adequate environmental flows can all improve a region's capacity to adapt to climate change impacts.

[2] In the remainder of the document, references to Central America include Costa Rica, Nicaragua, Panama, Honduras, and El Salvador, as well as Mexico.

The World Bank is mapping climate change data[3] as well as its possible impacts on power systems[4] and adaptive strategies to counter adverse risks.

Typically the time scale involved with climate change exceeds the lifetime of equipment installed during a rehabilitation project. The operating demands might be predicted however, with more variability and more extreme weather to be expected. Integration of other, intermittent, renewable energy sources will have to be factored in as well. Future hydropower rehabilitation projects must consider these factors in combination with other demands on water infrastructure caused by climate change, including the values at risk and vulnerability of stakeholders as well as other project-specific risks.

[3] The Climate Change Knowledge Portal http://sdwebx.worldbank.org/climateportal/

[4] Hands-on Energy Adaptation Toolkit (HEAT) http://www.esmap.org/esmap/node/342

2 REPORT OUTLINE

Section 1 provides a concise summary of the results of the study and includes an overview of the conclusions as well as lessons learned based on the assessment of the case studies.

Section 2 gives the context for the study including the definition of a set of hydroelectric project development options as background to related discussions of rehabilitation later in the report.

Section 3 provides an overview of the contents of this report.

Section 4 discusses the development and application of an assessment tool to facilitate the Rapid Assessment of Regional Hydropower Inventories. This assessment tool has been applied to a data base/inventory of generating station information in the African and Central American regions to identify possible candidates for rehabilitation. The characteristics of the two inventories are outlined in the section and details of the approach and the results of the application of the tool to the two regions are given in Annex A.

Section 5 presents a screening-level economic assessment model which quantifies potential costs and benefits associated with hydropower rehabilitation, concluding with generally accepted economic parameters. Details of the development of the economic model are given in Annex B.

Section 6 summarizes the application of the economic model to the two data base/inventory of generating station information for the two regions (Africa and Central America). The application of the economic model is not intended to provide site-specific economic parameters for each station since there is insufficient information in the data base for this. The objective of modeling is to provide an order-of magnitude Market Assessment of the potential for rehabilitation based on the limited data available in the data base.

Section 7 presents a summary of the important elements of a number of case studies involving historical Rehabilitation and Expansion Projects. The section is the source of a list of overall Lessons Learned which is presented in the Conclusions section.

Section 8 is a summary of issues which covers the spectrum of Incentives to Barriers associated with the rehabilitation of hydro projects under three broad categories: Technical, Financial and Environmental / Institutional.

Section 9 contains a summary of the conclusions reached in the study.

3 RAPID ASSESSMENT OF REGIONAL HYDROPOWER INVENTORIES

Details regarding the Rapid Assessment Tool that has been developed to screen the data base for projects can be found in Appendix A. the results of which application can be found in the next section.

3.1 Data Base

The UDI World Electric Power Plants Data Base[5] (WEPP) has been used as the universe of hydropower plants in Africa and Central America. The WEPP data base is a comprehensive, global inventory of electric power generating units. It contains ownership, location, and engineering design data for power plants of all sizes and technologies operated by regulated utilities, private power companies, and industrial or commercial auto-producers in every country in the world.

The version that was purchased includes the best data available to the publisher as of March 2009. For this study generating stations are called “plants” and the plants are composed of individual generating “units” which can be examined individually in terms of rehabilitation. Characteristics of units can vary in terms of capacity and year of commissioning so this allows a more accurate assessment to be carried out.

[5] http://www.platts.com This data base is published by Platts, a division of The McGraw Hill Companies, Inc.

4 REGIONAL INVENTORIES

The characteristics of the Africa and Central America WEPP data bases were examined as a preparatory step to the application of the Rapid Assessment Tool. The following sections discuss the key characteristics of the fleet of generating stations making up the two regional data bases.

4.1 Unit Size and Age

Table 4.1 gives the statistical properties of the fleet of generating plants in the data base for the two regions under consideration. Plants reported to have an installed capacity greater than 10 MW have been included in the preparation of this table.

Table 4.1 Regional Data Base Plant Characteristics

Region	Africa		Central America	
Number of Plants	137		109	
Total Capacity – MW	22,654		15,465	
Parameters	Capacity *(MW)*	Age *(Years)*	Capacity *(MW)*	Age *(Years)*
Minimum	10	3	10	2
Maximum	2100	82	2,430	106
Mean	165.4	36.2	141.9	34.9

The distribution by unit size for Africa and Central America can be found in Figure 4.1. Smaller units dominate the distribution in both regions with approximately 17% of the units in Central America being less than or equal to 10 MW. In Africa the comparable number is 15%.

Further, one can see the cumulative age distribution of the existing fleet in both regions in Figure 4.2. Here it can be seen that there has been a continuous expansion of the hydropower capacity in Central America, whereas Africa has seen the investments level off the last 20-30 years after a boom that started around the 1950's. The total installed effect is greater in Africa is than in Central America, which partly reflects the differences in size of the two regions.

Figure 4.1 – Unit Size Distribution for Africa and Central America.

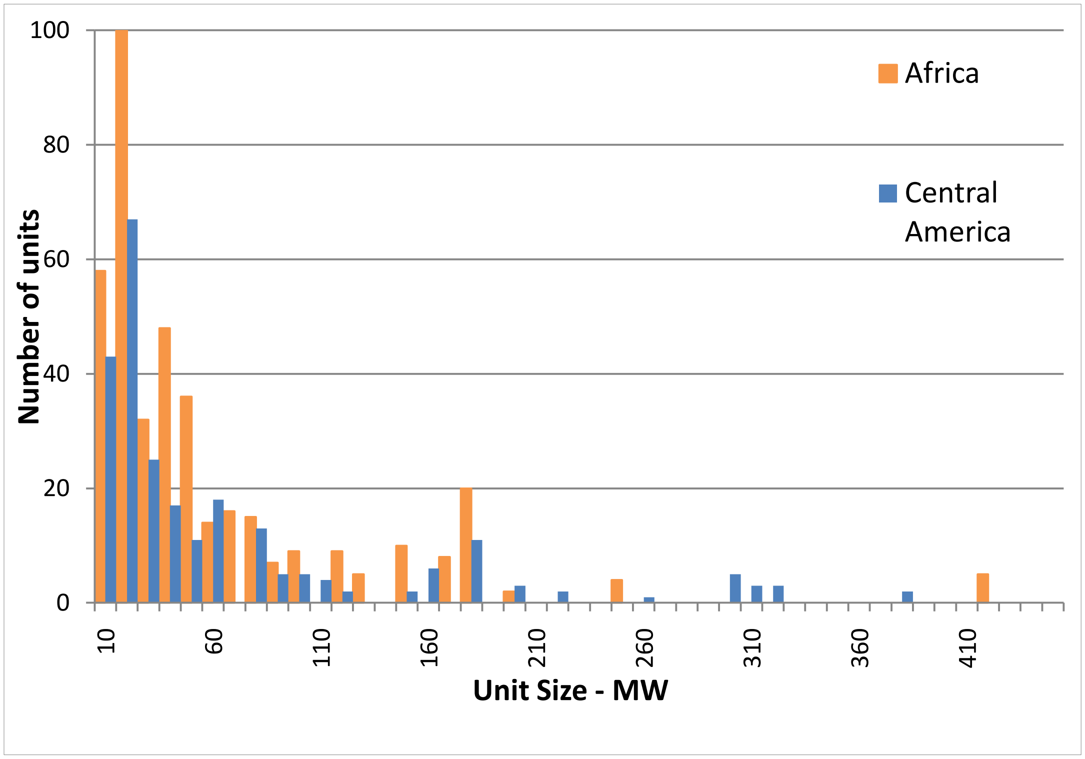
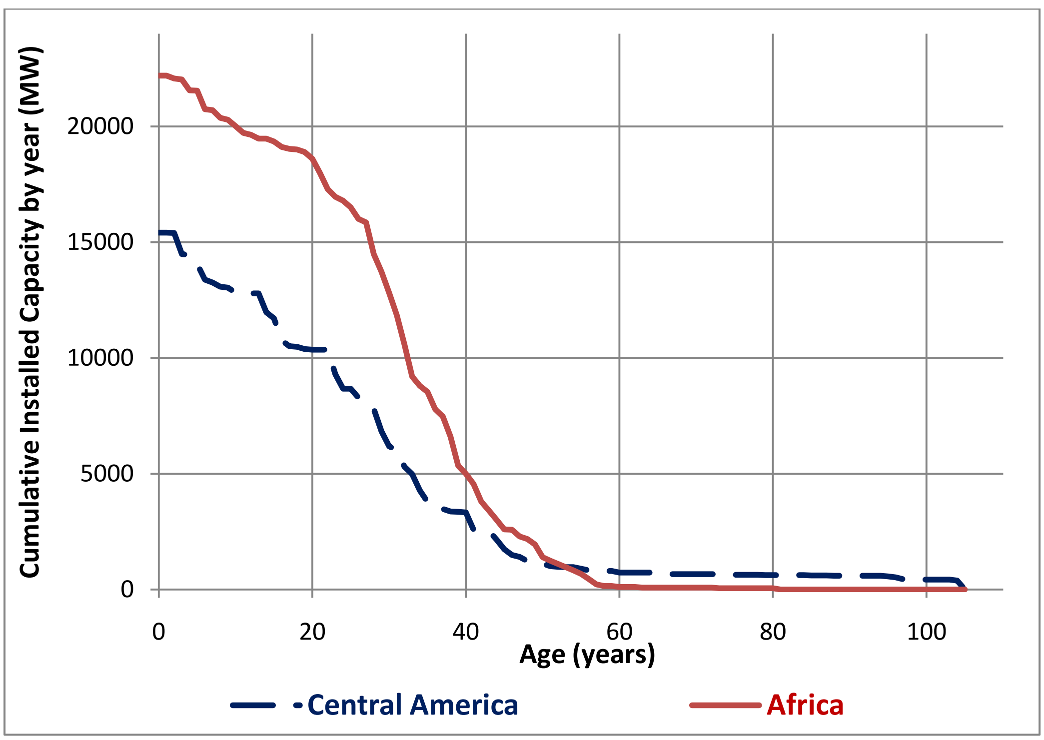


Figure 4.4 – Cumulative Unit Age Distribution for Africa and Central America.



If one compiles the data behind these cumulative charts, one can determine how many MW of unit capacity will move into given age ranges each year. These values are summarized in Table 4.2. This is an important aspect of the evaluation as it indicates that the number of MW of capacity that will reach a benchmark age of 35 years is expected to double in the next 10 years.

Table 4.2 – Cumulative Capacity Reaching 35 Years of Age Going Forward

Year	Cumulative Capacity - MW > 35 Years of Age	
	Africa	Central America
Current 2010	8528	3779
2015	12819	6186
2020	16506	8670
2025	18595	10363
2030	19353	11711
2035	20013	12809
2040	21540	14060
2045	22190	15416

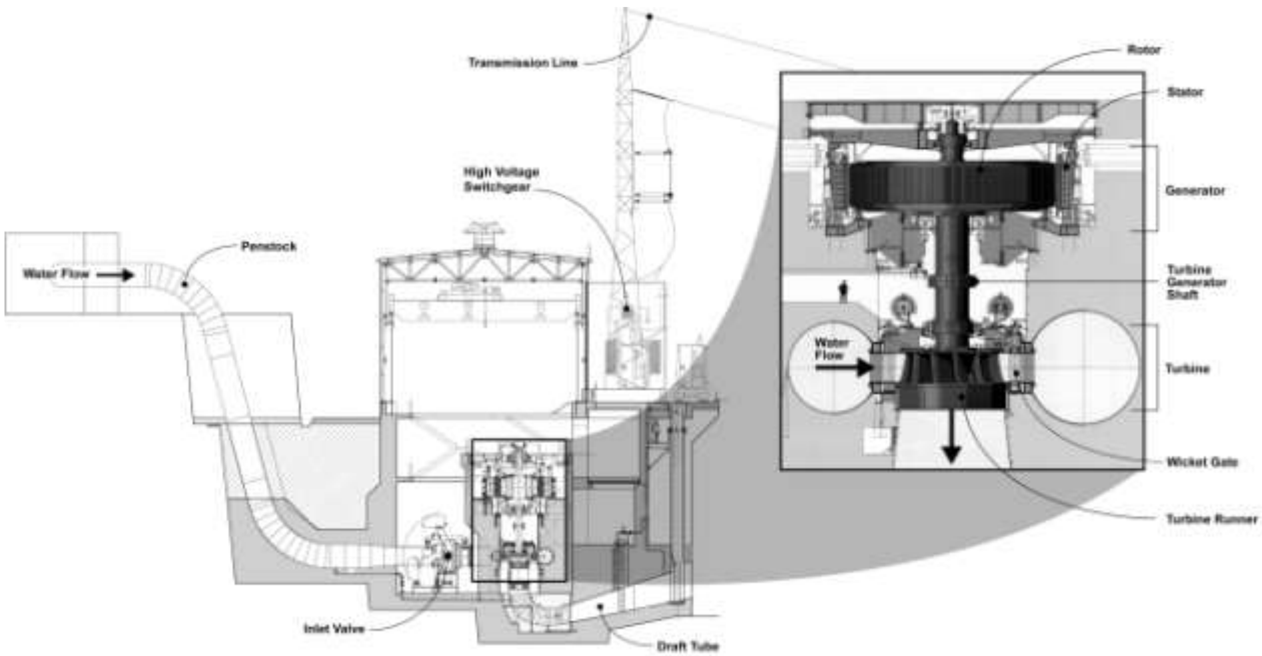
Assuming that a rehabilitation with an upgrade could yield a conservative 10% increase in performance in combination with recovery of degraded performances (efficiency, availability and reliability) and changes in technology (efficiency and output). This would mean that a 1250 MW of additional effective installed capacity can be gained through rehabilitation of all units in the two regions, currently 35 years of age or older. This number will double over the next decade.

4.2 Factors Affecting Rehabilitation

Rehabilitation is complex, and involves many engineering terms. The following section is to be considered as an introduction to terms one might encounter in technical reports. The impacts of age and operating conditions in terms of the various components are discussed below.

As a roadmap, the principal components of a typical hydraulic turbine (Francis) are shown in Figure 4.1 below.

Figure 4.1 Typical Hydroelectric Station Configuration for a Francis turbine.



4.2.1 Impacts of Age and Operating Conditions

Turbines -The impacts of age and operating conditions leading to deteriorating performance are well documented for hydraulic turbines. The primary concern is that turbine blades / runners can suffer from cavitation pitting damage, mainly on the suction side of the blades near trailing edge or, in the worst case, near the leading edge of the blades. Other elements of the turbine could also be subject to cavitation damage, most notably the wicket gates. Runner blade cracking can also be a concern related to issues including metallurgical changes and fatigue from fluctuating loads due to cavitation damage or vortex shedding. Lastly, high sediment loads with significant amount of hard deposits like quartz can wear away exposed metal parts. This phenomenon is referred to as abrasion and typically affects the runner and wicket gates.

Generator Stator Windings-Stator windings are considered to be a key age-based indicator of generator condition and considerable study and technical literature have been devoted to understanding the factors which influence winding life. Based on historical stators windings experience, statistical data indicates that stator windings should generally provide 45 years (or more) of reliable operating life. A review of operating records and reports would have to be carried out on a site-specific basis to determine the actual soundness of the stator windings

Generator Rotor-A key element associated with the rotor other than the windings is the shape and alignments as it affects the airgap between the rotor and stator during operation. Improper performance during transient events such as field flashing, synchronization, over-speed, etc – under certain circumstances could lead to a damaging rotor/stator 'rub'. If 'indicators' on the unit operation show potential problems then a comprehensive program of dynamic monitoring and analysis of the unit geometry and mechanical response – i.e. airgap monitoring, vibration monitoring, etc. may be required.

Bearings-The shaft and bearings can take various configurations depending on the type and manufacturer of unit. Many problems have been experienced with bearings and it is important to monitor the bearing temperature. A key consideration with regard to bearings is that in a rehabilitation involving a significant upgrade the ability of the existing bearing to take the load has to be carefully considered.

Lubrication – Mineral oil & grease has long been used as a standard for lubrication of equipment such as bearings, bushes, wicket gates journals, valve trunnions, governing oil pack, Kaplan runner hub etc. After years of operation, there is a potential risk of leakage, which may lead to loss of lubrication and thus damages plus the risk of polluting the environment.

Change of operating pattern – Initially designed for "base load" operations, some units are nowadays tackling "peak load" needs and other ancillary services such as frequency regulation, support of other intermittent renewable sources (wind, solar) etc. This increases the number of Starts & Stops per year from few dozens per year to several hundreds per year, which have accelerated aging effects through thermal cycling phenomena (e.g. generator) or fatigue issues (e.g. runner, mechanical parts)

4.2.2 Lack of O&M & Spares

A review of selected data has been undertaken to assess the typical operation and maintenance (O&M) cost of hydroelectric projects in North America. These expenditures can vary widely, depending on a variety of factors including location, capacity factor, generation strategy, manned versus unmanned station, type of plant (reservoir or run-of-river), annual production (MWh), number of Starts & Stops, etc. Typical O&M costs as a function of station capacity were described using the following power functions based on North America experience.

Benchmark Function - Annual O&M Cost (2009 USD) = 105,600 x Installed Capacity (MW) $^{0.64743}$

Best Practices Function - Annual O&M Cost (2009 USD) = 58,100 x Installed Capacity (MW) $^{0.64743}$

Annual O&M for a 100 MW generating station would typically be $2.1 million as a benchmark value and $1.2 million as a best practices value, a reduction of 55%.

There is anecdotal evidence that such norms are not being met in many areas of Africa due to a lack of resources and funds. This could lead to a significant reduction in unit availability as well as operating problems that are manifested in earlier equipment failure than would normally be expected under a "Normal" or "Best Practices" O&M scenario.

4.2.3 Reliability, Availability and Outages

Reliability and availability of power as well as scheduled outages versus forced outages are easily confused.

In this report, *reliability* refers to the time a hydropower plant is ready to deliver power. That is;

Reliability = 8760 hours/year – hours of forced outage

Here forced outage refers to unplanned stops due to failing equipment, mismanagement etc.

Availability also takes into account scheduled outages (i.e. maintenance etc). This gives;

Availability = Reliability –hours of scheduled outage

Key parameters that influence outages are for example; plant factor, sediment inflow, storage capacity of reservoir, load patterns etc.

Transmission capacities and the overall power mix in the grid impacts the overall situation, and might also spill back to a power station and lead to forced outages.

Blackouts refer to forced outage, where brownout refers to loadshedding that can be planned or happen automatically

Table 4.2 Suggested classification for assessment of plant availability (due diligence).

Plant Availability		Assessment
(hours/year)	%	
7000 or more	A>80%	Good
Between 7000 and 6000	68%<A>80%	Poor
Less than 6000	A<68%	Very Poor

4.3 Coarse Screening of Hydropower Station Data Bases

Given the obvious importance of age and its relative ease of determination, a coarse screening model was developed for application to readily available hydropower station data bases. The following sections outline the basis for the screening and an overview of the results with the details included in an annex.

4.3.1 Objectives for Screening

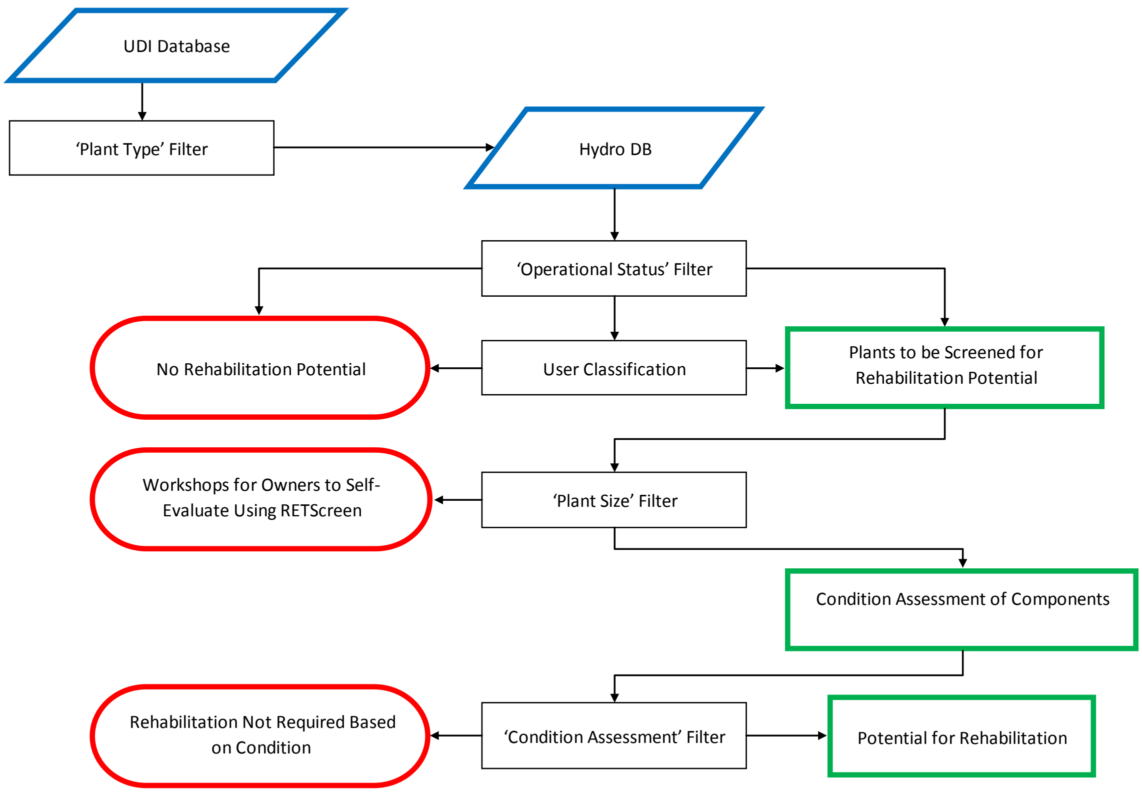
The screening is intended to be used to carry out an initial assessment of the inventories of hydroelectric stations to identify lists of potential candidate plants for rehabilitation. This could then be further qualified through additional site-specific economic assessments using calculation procedures similar to those outlined in Sections 5 and 6 of this report.

4.3.2 The Rapid Assessment Tool

Initial work on the rapid assessment tool, referred to herein as the Hydropower Assessment Tool (HAT) was carried out by an independent consultant, Terry Molstad, P.Eng. Figure 4.6 illustrates the basic procedure structure for HAT.

In order to apply the HAT to the hydropower plants data base in Africa and Central America, an automated screening spreadsheet was created using MS Excel. Through a series of macros, this spreadsheet first selects the candidate hydropower plants from the data base of power plants. It then applies the condition assessment rules to each of the units for each of the candidate hydropower plants and assigns rapid assessment ratings to each component of each power plant.

Figure 4.6 – HAT Procedure Structure



There are four filtering processes, and each step can be run by clicking the appropriate button in the spreadsheet.

1. Plant Type. This step takes the raw data and filters out those that are hydro generating plants. Hydro line items are dropped into the '1 - Hydro DB' worksheet.

2. Operational Status. This step creates three lists from the 'Hydro DB' list: Those that are in commercial operation, those that are not yet completed, and those that are completed but not operating. Manual intervention is needed to make judgments on any plants in the completed but not operating category that should be added to the list to be screened.

3. Plant Size. This step filters out those plants which are smaller than 10 MW. 10 MW was selected as it was judged as being a lower limit on plant size which could be attractive for International Financial Institution (IFI) funding. Other sources of funding would be more commercially attractive for the smaller unit sizes. Those that are smaller are dropped into the '3 - RETScreen Workshops' worksheet. Those that are greater are dropped into the '3 - To Condition Assessment' worksheet.

    4. Condition Assessment. This step takes the line items from worksheet '3 - To Condition Assessment' and creates an output sheet showing a rapid condition assessment of each unit called '4 - Condition Assessment'. This step also establishes the opportunities for turbine and turbine/generator upgrades.

4.3.3 Hydro Asset Trigger Age of Components

Table 4.3 shows the trigger ages for rating the various components which was developed for the HAT. The ratings are used to classify the component condition based on age without reference to a condition assessment or site-specific knowledge of the level of maintenance the component may have had.

Table 4.3 Rapid Assessment Ratings

Plant Subsystems	Economical Lifetime (*years*)	Technical Lifetime (years)	Rapid Assessment Rating Good (<=)	Fair (<=)	Poor (>)
Electrical Installations					
Generators, transformers	25-40	30-60	**25**	**45**	**45**
High voltage switchgear, auxiliary electrical equipment, control equipment	20-25	30-40	**20**	**35**	**35**
Batteries, DC equipment	10-20	20-30	**10**	**25**	**25**
Mechanical Installations					
Turbines					
Kaplan and Francis turbines	30-40	30-60	**30**	**45**	**45**
Pelton turbine	40-50	40-70	**40**	**55**	**55**
Pump turbine and Storage pumps	25-33	25-50	**25**	**33**	**33**
Gates, butterfly valves, special valves, cranes, auxiliary mechanical	25-40	25-50	**25**	**37**	**37**
Civil Works					
Dams, canals, tunnels, caverns, reservoirs, surge chambers	60-80	80-150	**60**	**100**	**100**
Powerhouse structures, water catchment, spillway, sand traps, penstocks, steel linings, roads, bridges	40-50	50-80	**40**	**65**	**65**

The trigger ages given in Table 4.3 are not universal to all regions of the world but are dependent on the design and manufacture of the equipment, the O&M and the conditions under which the equipment and structures have to operate. The trigger ages can be affected, among others, by the following elements:

- Original choice of configuration, quality of the major equipment and the care with which it was installed
- Existence of a proper maintenance programme
- Operational pattern (start & stop vs. base load)
- Extreme operating conditions
- Sediment load

4.3.4 Overall Screening Results

The results of applying the HAT to the hydropower plant data bases in Africa and Central America are shown in Tables 4.5 and 4.6. These tables show that the coarse screening indicates there are 45 hydropower plants in Africa and 34 in Central America, respectively that are indicated to be in "poor" condition and hence could be in needed of rehabilitation work. Detailed information at the plant level for Africa and Central America are given in Annex A.

Table 4.4 Country Summary Africa.

Country	Number of Plants/Units Assessed to be in Poor Condition			
	10-50 MW	51-250 MW	Over 250 MW	Total
ALGERIA	1	2		**3**
ANGOLA	1	1		**2**
CAMEROON		1	1	**2**
CONGO	2	5	1	**8**
CONGO REPUBLIC		1		**1**
COTE D'IVOIRE		4		**4**
EGYPT			2	**2**
ETHIOPIA	3	2		**5**
GABON	1	2		**3**
GHANA		1	1	**2**
GUINEA	1			**1**
KENYA	2	2		**4**
MADAGASCAR	1	1		**2**
MALAWI	1	2		**3**
MALI	1			**1**
MOROCCO	6	3		**9**
MOZAMBIQUE	1	1	1	**3**
NAMIBIA		1		**1**
NIGERIA			2	**2**
REUNION	2			**2**
SOUTH AFRICA		2	2	**4**
SUDAN		1		**1**
TANZANIA	1	1		**2**
TUNISIA	1			**1**
UGANDA		1		**1**
ZAMBIA		1	2	**3**
ZIMBABWE			1	**1**
Total	**25**	**35**	**13**	**73**

Table 4.5 Country Summary Central America.

Country	Number of Plants/Units Assessed to be in Poor Condition			
	10-50 MW	51-250 MW	Over 250 MW	Total
COSTA RICA	1	4		**5**
EL SALVADOR		3		**3**
GUATEMALA		2	1	**3**
HONDURAS	2	1		**3**
MEXICO	8	12	6	**26**
NICARAGUA	2			**2**
PANAMA	4		1	**5**
Total	**17**	**22**	**8**	**47**

4.3.5 Limitations

The major limitations of this approach are that there is no certainty that the age indicated in the database represents the actual condition of the individual units. Further, there is no indication if the unit may have already been rehabilitated. As a matter of fact, one of the case studies represents units that have not been updated in the data base.

Due to the scope of this study it was not possible to have information on the recent output of the station which could indicate if the units are functioning in an expected manner. This could also have provided valuable information on which to base an economic analysis as part of an assessment of rehabilitation potential.

In summary the HAT gives a broad indication of the possible condition of individual components in a station on a country by country basis but this assessment is done without site-specific data.

5 FEASIBILITY OF HYDROPOWER REHABILITATION

5.1 Approach to Rehabilitation Analysis

Typical rehabilitation analysis for hydroelectric generating stations balances the consequences of outage against capital costs to manage long-term plant reliability at minimum cost. The type of rehabilitation being considered in this assessment is concerned only with major electrical and mechanical equipment and not with the civil aspects of the generating station. Civil works can be part of the upgrade as well. Sometimes one will want to improve the waterway capacity to reduce losses or increase the discharge, move the intake to increase head, reduce the sediment load entering the system or deal with dam safety issues.

The impacts of upgrading components must be evaluated by its impact on the entire system. As for Greenfield projects, any additional power must have a market (PPA or other) and capacity to reach that market (transmission). Flow changes downstream may also affect other stakeholders, etc.

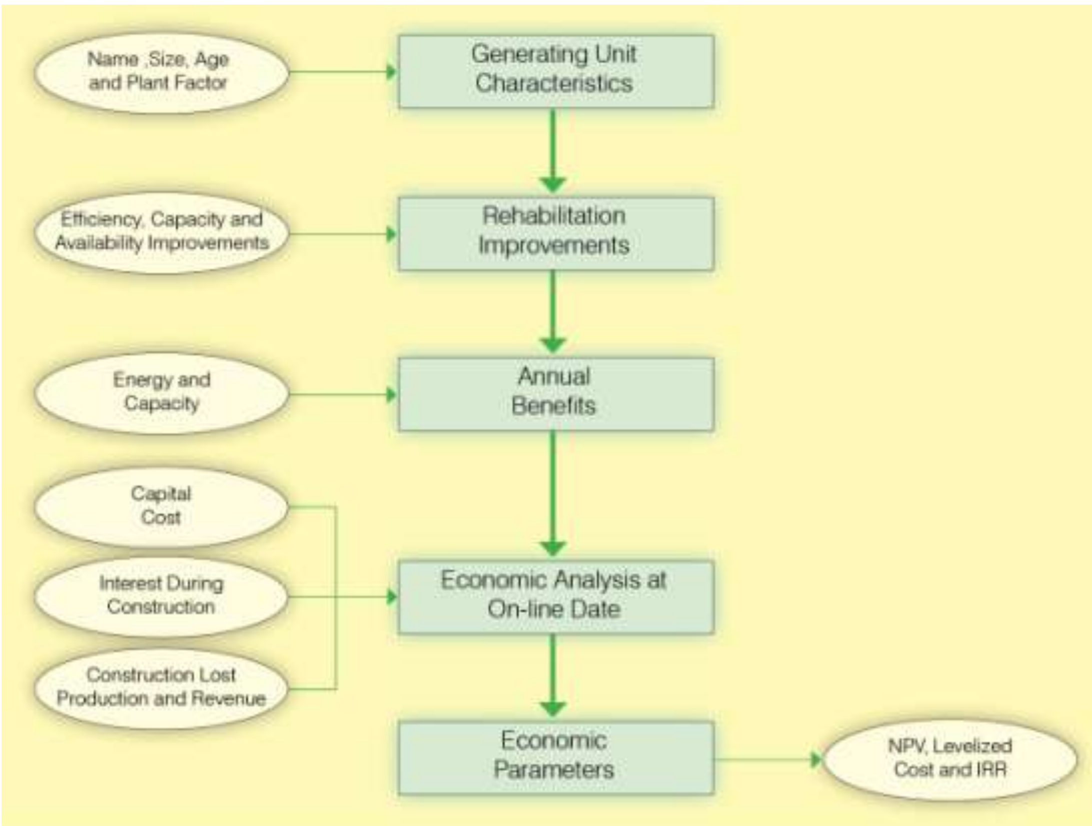
Typical tasks associated with rehabilitation analysis include:

- A site visit to the powerhouse to inspect the generating unit preferably during a period of regular maintenance.
- Review of previous turbine / generator condition assessments and maintenance records and interviews of plant maintenance personnel
- Undertake condition assessment of equipment as this is an important part of rehabilitation analysis. This information can be used to establish a representative, as opposed to physical age, of the equipment.
- Develop cost estimates and schedules for life extension and / or upgrade options
- Develop efficiency curves for the current units as the units with life extension or upgraded options based on parameters established from previous experience (Note that Section 2 provides a definition of the life extension and upgrade options as they apply to rehabilitation)
- Finalize performance characteristics in terms of efficiency and capacity for possible life extension / upgrade options
- Quantify the cost streams associated with the various rehabilitation scenarios. It would be good practice to: a) assume the lower end of physical condition ranges in cost estimation; and b) assess fairly high (e.g. 10% or higher) physical contingencies where the client has not had experience in rehabilitation and particularly if the unit has not been dismantled prior to cost estimation (or if it is the first in a multi-unit rehabilitation).
- Provide an economic analysis of the life extension / upgrade option and present the benefits and costs of each.

5.2 Approach Applied to Regional Data Base

The current study examines the potential feasibility of rehabilitation for the fleet of generating units in the African and Central American regions of the world that are part of plants with a total installed capacity of over 10 MW. Therefore a simplified approach has been adopted since inspection, condition assessments and maintenance and operating information was not available for the respective generating stations. Figure 5.1 gives a flow chart of the generic assessment adopted to evaluate the regional data available in the data base as outlined in Section 4 above.

Figure 5.1 Flow Chart of Rehabilitation Assessment



5.3 Upgrade Potential and Benefits

The following sections discuss the relationship between the types of work needed on the primary components of a hydropower plant during its lifecycle and the expected benefits. Reference should be made to Figure 4.1, above, which indicates the main components of a hydraulic turbine. Other components not shown in the figure are briefly described as to their location in the following sections.

5.3.1 Turbines

Common problems with turbines include cavitation, blade cracking, rough operation and seal clearance deterioration. If we know the age of the equipment we can estimate the life extension and upgrade potential benefits based on age versus performance indicators. The performance indicators for turbines include efficiency, capacity (output) and hydraulic circuit losses.

Efficiency

Efficiency is the most important factor and upgrade potential can be broken out into three elements:

- Technology improvement as demonstrated by higher efficiencies today than 50 years ago
- Deterioration in efficiency due to age (wear and tear)
- Changes in hydrological conditions or operations could lead to changes in the operating range compared to initial design.

J.L. Gordon (2001) recommends that the technology change of turbine efficiency with time can be represented by the following equation:

$$\Delta\varepsilon_{year} = \left(\frac{1998 - y}{B}\right)^{x}$$

Gordon suggests that the gains in peak efficiency is asymptotical, so that a unit newer than 1998 has only relatively modest gains on the year 1998. (B) and (x) are constants depending on the runner type where (B) is 187 and (x) is 3 for a Francis turbine which was the type assumed in the analysis.

Gordon's equation has been used to estimate the turbine efficiency gain over time due to technology, assuming that the change has continued after 1998 up to today. Changes in technology associated with looking at the situation in future years (e.g. 2015, 2020 etc) were ignored since the gain would approach zero asymptotically as the efficiency can never be greater than 100%.

Technology gains in efficiency over time can be demonstrated by considering two years separated by a period typical for rehabilitation evaluation (e.g. 1960 to 2010). Assuming that Gordon's equation is applicable up to 2010, a difference in efficiency for this 50-year period would be in the order of 1.9%. This full improvement cannot be applied to an upgrade since only the runner (plus perhaps a few other modifications) would be carried out. A reasonable assumption would be that 50% of the technology improvement would be applicable to an upgrade, which was assumed in this analysis.

The above analysis refers generally to peak efficiency and additional benefits could be achieved from a turbine with a design tailored to the specific range of flows and heads historically encountered at the site. For a detailed analysis of the efficiency gain, which this study has not done, an average weighted efficiency needs to be considered with a weighing formula, which approximately reflects the distribution of energy generation on part load, peak and overload conditions.

Degradation in turbine efficiency due to the wear and tear associated with the age of the unit was assumed to be 0.06% per year. It was assumed that 100% of this degradation would be recovered in an upgrade scenario and 70% would be recovered in a life extension scenario.

Discharge Capacity

The maximum discharge capacity of the machine can degrade over time just as efficiency is found to degrade. A new runner can restore original capacity and in most cases the new technology can provide the opportunity to increase the capacity (efficiency and output) above the original design. The typical increase in capacity from rehabilitation experience has been taken as 12% over 80 years as an average between potential efficiency improvement (up to 5%) without additional discharge; and potential output improvement (up to 30%) with additional discharge in regards of cavitation limitation from unit setting.

An additional benefit of new hydraulic designs is that they are more adapted to pressure fluctuations, resulting in an increased operational range. This applies especially to Francis turbines with older design.

Hydraulic Losses

Breakdown in losses between the various components (draft tube – runner – wicket gate) of the turbine show that the runner accounts for only 35% to 40% of the losses in a hydraulic turbine. Therefore, if only a runner is replaced then the impact is not as large as if the entire unit were replaced. The cost of the unit replacement (upgrade and not life extension) is considerably higher as outlined in subsequent sections of the report.

5.3.2 Generators

The key condition considerations for generators are stator windings, stator cores, rotors , exciters and ventilation losses.

5.3.3 Stator Windings

Capacity - The major electric upgrade which is applied to generators is the rewinding of the stator. Given the improvements in technology the required thickness of insulation is reduced in comparison with the original insulation. Changes in technology could be expected to have a rough timeline on the types of winding in use as outlined below:

1930 - 1955 - Soft installations – initially shellac-bonded mica splittings evolving into asphaltic-bonded mica splitting. For windings pre-1955, a 15 % capacity (output) increase keeping the same dimensions, is probably realizable with a switch to modern windings.

1955 – 1970 - Gradual introduction of synthetic resins – first polyester then epoxy, silicon and polyurethane with progression from Class B to Class F insulation. For ~1955 - ~1970 capacity increases of 7.5 to 10% are probably possible as true thin, 'hard' class F insulation was not generally applied.

1970 onwards - Virtually all stator windings use advanced polyester resin or epoxy resins in Class F 'hard' insulation systems. Post ~1970 minimal capacity gains are possible through refinements in insulation thickness / voltage gradients / thermal transfer etc.

Efficiency - It should be noted that generator efficiency has not changed much over this time horizon. The main improvement has been on the capacity size since modern insulation has allowed higher heat levels and given more room for the copper windings. For this study a small increase in efficiency could be anticipated due to newer technology and this has been assumed as a total of 0.5 % over the period from 1930 to today.

5.3.4 Stator cores

New materials allow lower iron losses in stator core compared to the old generation of materials. The increase in efficiency, which will result of the use of this new technology, has to be considered in case of upgrade.

5.3.5 Rotors

The total replacement of a rotor is rare so the scope of work would be limited to the rehabilitation of the pole windings and connections which would yield another 30 years of service. This has been assumed as part of the additional cost which would extend the service life but it would not contribute to an increase in output.

5.3.6 Exciters

Generators require a direct current to energize the magnetic field and this is normally obtained from the exciter. Rehabilitation offers a chance for the existing exciters to be replaced with more adapted excitation technology. This has been assumed as part of the additional cost which would extend the service life but would not contribute to an increase in output.

Static Excitation: available for all voltage (up to thousands of amps), this technology allows quick time response, high level features, such as PSS. Static excitation is best suited for medium to large hydro schemes.

Brushless Excitation (rotating diodes): available for low voltage only (up to 40 or 50 Amps), this technology is lower performing but requires less investment and maintenance (no carbon dust to clean on a regular basis). Brushless excitation is best suited for small to medium hydro schemes.

5.3.7 Ventilation

The main target is to reduce the ventilation losses of the generator, thus improving the efficiency. The challenge is to reduce the cooling air flow without increasing the active parts' (stator and rotor windings) temperatures. Such analysis can be applied to generators with old ventilation system concept. More focus on medium/high speed generators (>250rpm). Potential in efficiency improvement up to 0.3% can be expected. To achieve such results, it is mandatory to optimize key parameters such as cooling air velocity at the outlet of the fan, relative speed of the air at rotor inlet, flow distribution, heat transfer coefficients.

5.3.8 Oil Free Lubrication

Leakages of mineral oil and grease pollute the river and have an impact on irrigation, water supply, aquatic life, fishing etc. To mitigate the potential risk, it is possible to upgrade the following components with oil free lubrication:

- Water lubricated bearings
- Oil free Kaplan runner (water filled hub)
- Self-lubricated bushings (Wicket gates, Kaplan blades, Valve journals or trunnions, Vane rollers)
- Governing system with biodegradable and low toxic oil.

5.3.9 Step-Up Transformers

The majority of the failures can be traced to breakdown of insulation. The transformers would have to be replaced to match the increase (upgrade not life extension) in output from the turbine and generator. The efficiency gain would be small and has been neglected in this analysis.

5.3.10 Supporting Systems (Balance of Plant)

These components are highly impacted in term of availability & reliability rate when getting older. Replacement of the supporting systems can normally be done as part of the life extension of the major components. This has been assumed as part of the additional cost of the rehabilitation which would extend the service life but would not contribute to an increase in output.

5.3.11 Overall Reliability

Restoring reliability (and availability) of energy is a key benefit of any life restoration or upgrade. In assessing the feasibility of rehabilitation, the overall reliability and availability of the units has to be well quantified as this will have a major affect on the economics of the project. At a certain stage in the life of any installation as the availability decreases, "extension of life" becomes "prevention of death". There will come a time, with no rehabilitation and capital investment in the replacement of components, that the unit simply ceases working. Obviously, as that point is reached, particularly in cash-starved developing countries, the economic attractiveness of rehabilitation will be very high since (in the worst case scenario) an entire hydroelectric installation can be revitalized for the price of rehabilitation.

Warning signs of future problems could include such things as rough operation caused by cavitation and / or sediment passage damage, lack of spare parts leading to repeated failures and reduced reliability as well as availability and scavenging from units with more serious operational problems to keep better units operating. These issues are very site specific and are not captured in the generic data bases that were available for the African and Central American regions.

Availability can decrease particularly in developing countries where O&M budgets and spare parts availability are significantly constrained in comparison to developed countries. For a hydropower plant with a sufficient reservoir, typical reliability can reach 98% for well maintained equipment in developed countries but typical values for developing countries are not well documented. In case of most run-of-river schemes, maximum reliability is more in the range of 95%. Based experience, reliability easily drops 10 percentage points (i.e. 88% or 85%) for older equipment. In addition, the World Bank looked into their experience and indicated that a global value for EEPCIO of 60-70% has been quoted. A lower value of 75% reliability at 60 years was therefore examined in a sensitivity assessment.

See section 4.2.3 above for a more detailed explanation of Reliability, Availability and Outages.

5.4 Rehabilitation Scenarios

The following two scenarios were examined in the assessment: life extension and upgrade.

5.4.1 Life Extension

The benefits of life extension are limited to rehabilitating the turbine to close to the original equipment specification. A clear limit on life extension is that it does not take advantage of changes in turbine technology but seeks only to extend the operation of the units with more or less the same output that was inherent in its original equipment. This is not true for the generators since a stator rewind would be done with modern materials. Life extension would therefore typically include:

- Generator and turbine dismantling
- Generator stator rewind
- Generator mechanical rehabilitation (generator, excitation)
- Turbine rehabilitation (runner, seals, wicket gates, speed governor)
- Unit auxiliaries rehabilitation
- Turbine and generator reinstallation and testing

There is also the issue of the stator core and the generator poles; however these are uncertainties and can be lumped in with the stator rewind.

The overall benefits attributed to rehabilitation have been broken down into an efficiency recovery of the losses associated with aging, a capacity recovery of associated losses due to aging and finally an availability recovery. The benefits from a change in turbine or generator technology have been assumed to be zero for a life extension. Variations associated with turbine efficiency degradation have been assumed to be linear with time and 50% are assumed to be recoverable in a life extension scenario. The overall benefits for life extension are summarized in terms of the energy, capacity and availability benefits, separated on the basis of “technology gain” and “degradation recovery”, as shown in Table 5.1. It should be noted in Table 5.1 that the technology changes use the year of unit commission or last rehabilitation to determine the potential gain while degradation recovery uses age to determine the potential benefit since degradation is related to age. This is an important aspect when looking forward at how the benefits change if the rehabilitation is postponed from 2010 to 2015, for example.

Table 5.1 Summary of Life Extension Benefits**

		Year of Unit Commissioning or Last Rehabilitation											
	Year	**2010**	**2000**	**1990**	**1980**	**1970**	**1960**	**1950**	**1940**	**1930**	**1920**	**1910**	**1900**
Technology Gain													
Turbine Efficiency	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Turbine Capacity	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Generator Efficiency	%	0.0%	0.2%	0.3%	0.5%	0.6%	0.8%	0.9%	1.1%	1.3%	1.4%	1.6%	1.7%
Generator Capacity	%	0.0%	0.0%	0.0%	0.0%	7.5%	7.5%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Unit Availability	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Age of Unit from Commissioning Date or Last Rehabilitation											
Degradation Recovery	**Age**	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	80	**90**	**100**	110
Turbine Efficiency	%	0.0%	0.4%	0.8%	1.3%	1.7%	2.1%	2.5%	2.9%	3.4%	3.8%	4.2%	4.6%
Turbine Capacity	%	0.0%	0.4%	0.8%	1.3%	1.7%	2.1%	2.5%	2.9%	3.4%	3.8%	4.2%	4.6%
Generator Efficiency	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Generator Capacity	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Unit Availability	%	0.0%	0.3%	1.1%	2.5%	4.4%	6.9%	10.0%	13.7%	17.9%	22.7%	28.1%	34.1%

** - Benefits are determined for Technology Gains based on the year of commissioning and for Degradation Recovery on the age which is important when considering reference years beyond 2011. Generator capacity gains are only taken into account if there is an increase at the turbine level.

5.4.2 Upgrade

The benefits of an upgrade are NOT limited to returning the turbine to close to the original equipment specification. Upgrades take advantage of changes in technology for both the turbine and generator.

Upgrade would typically include all of the modifications for the life extension listed above, plus:

- New turbine runner
- New generator in case of large output upgrade
- Allowance for additional turbine work (draft tube, intake)
- Ancillary benefits such as oil free lubrication, easier maintenance and operation etc.

It should be noted that the two scenarios are mutually exclusive and not additive.

The overall benefits of upgrade are summarized in terms of the energy, capacity (output) and availability benefits, separated on the basis of "technology gain" and "degradation recovery", as shown in Table 5.2.

Table 5.2 Summary of Upgrade Benefits.

		Year of Unit Commissioning or Last Rehabilitation											
	Year	**2010**	**2000**	**1990**	**1980**	**1970**	**1960**	**1950**	**1940**	**1930**	**1920**	**1910**	**1900**
Technology Gain													
Turbine Efficiency	%	0.0%	0.0%	0.1%	0.2%	0.5%	1.0%	1.7%	2.6%	3.9%	5.6%	7.6%	10.2%
Turbine Capacity	%	0.0%	1.5%	3.0%	4.5%	6.0%	7.5%	9.0%	10.5%	12.0%	13.5%	15.0%	16.5%
Generator Efficiency	%	0.0%	0.2%	0.3%	0.5%	0.6%	0.8%	0.9%	1.1%	1.3%	1.4%	1.6%	1.7%
Generator Capacity	%	0.0%	0.0%	0.0%	0.0%	7.5%	7.5%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Unit Availability	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Age of Unit from Commissioning Date or Last Rehabilitation											
Degradation Recovery	**Age**	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	80	**90**	**100**	110
Turbine Efficiency	%	0.0%	0.6%	1.2%	1.8%	2.4%	3.0%	3.6%	4.2%	4.8%	5.4%	6.0%	6.6%
Turbine Capacity	%	0.0%	0.6%	1.2%	1.8%	2.4%	3.0%	3.6%	4.2%	4.8%	5.4%	6.0%	6.6%
Generator Efficiency	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Generator Capacity	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Unit Availability	%	0.0%	0.3%	1.1%	2.5%	4.4%	6.9%	10.0%	13.7%	17.9%	22.7%	28.1%	34.1%

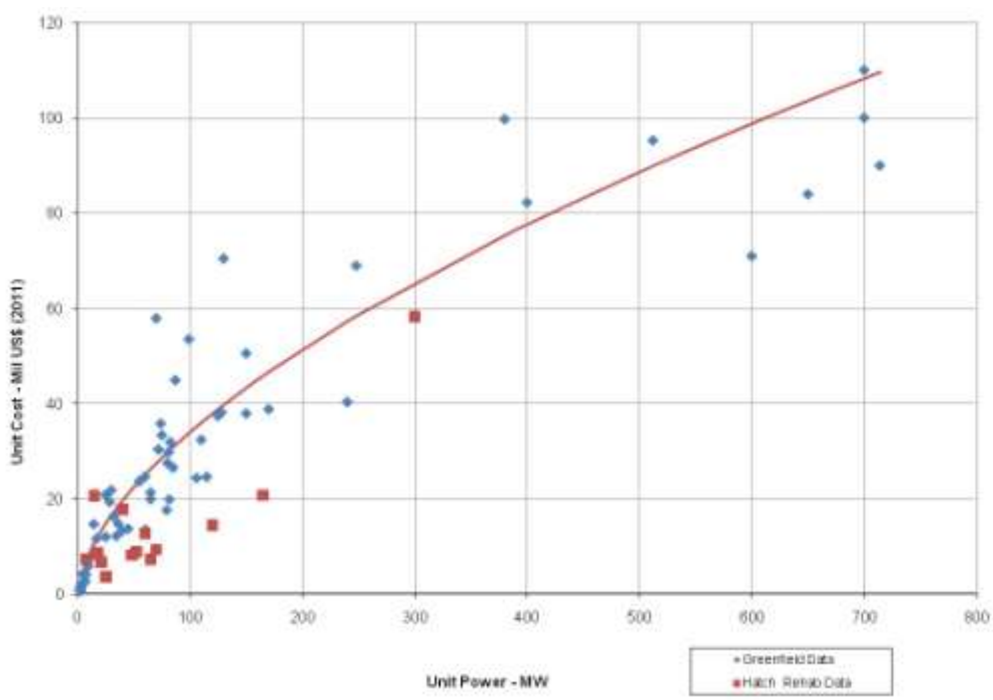
5.5 Investment Costs

The investment costs associated with life extension and upgrade alternatives have been related to benchmark Greenfield (i.e. new projects) costs for hydro projects since there is more data readily available to develop the benchmark cost functions.

Greenfield equipment costs relative to installed effect are given in the chart below and are based on available data for several rehabilitation projects where data is available. These have been plotted to derive a value for the fraction of the Greenfield costs incurred in undertaking either life extension or upgrade.

In order to get a clearer picture, one could deconstruct the installed effect into design head and discharge which would give a clearer correlation, but the data used lacks information detailed enough to do such analysis.

Figure 5.1 Typical Hydropower Equipment Cost Data (Greenfield and Rehabilitation)



There is a fair amount of scatter in both the Greenfield and rehabilitation costs but based on this available information the costs of life extension have been assumed as 60% of Greenfield costs while upgrade costs have been assumed as 90% of Greenfield costs. These values represent an average due to the fact that rehabilitation costs are directly linked to the scope of works definition and due to the fact that each project is unique.

5.6 Economic Analysis

The information on the potential for unit rehabilitation was compiled into a MS Excel Spreadsheet which includes the following key categories of parameter:

- Station Location and Unit Characteristics
- Rehabilitation Benefits at the On-line Date
- Rehabilitation Costs at the On-line Date
- Economic Indicators

Annex B gives more details on the economic analysis and provides the detailed results of the application of the analysis for the two regions. Section 6 provides an overview of the results of the economic analysis as it relates to the market analysis for rehabilitation.

6 MARKET ASSESSMENT

The economic analysis model outlined in Section 4 and Annex B gives the basis upon which, for generic information on the rates at which equipment deteriorates, rehabilitation can become economically viable. This was combined with the statistics of the generation fleets in Africa and Central America to yield an assessment of the current (2011) potential for economic rehabilitation and at 5 year increments over the next 20 years.

6.1 Results by Region

Table 6.1 summarizes the assessment by region based on the more extensive material available in Annex B. These tables describe the potential at an aggregate level per country for 2011, as well as details of the economic assessment for year 2025. Only the generating stations equal to or greater than 10 MW, and units which are judged to have a positive net present value (NPV) for life extension, are included.

Table 6.1 Economic Analysis of the Rehabilitation Potential for Africa and Central America by Year **

Reference Year	Scenario	Region	PV of Benefits (MUS$)	PV of Costs (MUS$)	NPV (MUS$)	Levelized Cost (US$/MWh)	IRR %
2011	**Life Extension**	Africa	$5,415	$2,872	$2,543	$69.70	15.7%
		Central America	$2,251	$1,616	$635	$74.13	16.0%
		Total	**$7,666**	**$4,488**	**$3,178**	**$71.47**	**15.8%**
	Upgrade	Africa	$8,063	$3,901	$4,162	$84.32	17.0%
		Central America	$3,195	$2,029	$1,166	$92.42	16.8%
		Total	**$11,258**	**$5,930**	**$5,328**	**$87.66**	**16.9%**
2015	**Life Extension**	Africa	$6,576	$3,183	$3,393	$67.30	16.5%
		Central America	$3,082	$2,094	$987	$73.46	15.9%
		Total	**$9,658**	**$5,277**	**$4,381**	**$69.87**	**16.3%**
	Upgrade	Africa	$9,350	$4,280	$5,070	$82.09	17.3%
		Central America	$4,176	$2,657	$1,519	$87.71	17.0%
		Total	**$13,525**	**$6,936**	**$6,589**	**$84.40**	**17.2%**
2020	**Life Extension**	Africa	$8,307	$3,679	$4,628	$65.04	17.5%
		Central America	$3,996	$2,439	$1,557	$68.06	17.0%
		Total	**$12,303**	**$6,118**	**$6,185**	**$66.27**	**17.3%**
	Upgrade	Africa	$11,186	$4,832	$6,354	$77.12	18.0%
		Central America	$5,167	$3,096	$2,070	$81.53	17.4%
		Total	**$16,353**	**$7,928**	**$8,424**	**$78.93**	**17.8%**
2025	**Life Extension**	Africa	$10,131	$4,073	$6,058	$61.17	18.8%
		Central America	$5,152	$2,890	$2,262	$64.64	17.9%
		Total	**$15,283**	**$6,963**	**$8,320**	**$62.60**	**18.5%**
	Upgrade	Africa	$13,211	$5,358	$7,853	$72.75	18.8%
		Central America	$6,333	$3,573	$2,760	$76.55	18.0%
		Total	**$19,545**	**$8,931**	**$10,613**	**$74.31**	**18.5%**

** Assuming that no rehabilitation takes place prior to reference year

6.1.1 Life Extension Scenario

Reading the results of the simplified economic analysis presented in Table 6.1 one can see that a US$ 2.9 billion investment in Africa can unleash benefits of US$ 6.4 billion in present value through life extension.

Similarly, as seen in table 6.2, similar results are given for Central America; investments of US$ 1.6 billion yield benefits of US$ 2.3 billion.

6.1.2 Upgrade Scenario

Table 6.1 also show the comparable information for the upgrade scenario which, for Africa, shows a US$ 3.9 billion investment producing present value benefits of US$ 8.1 billion.

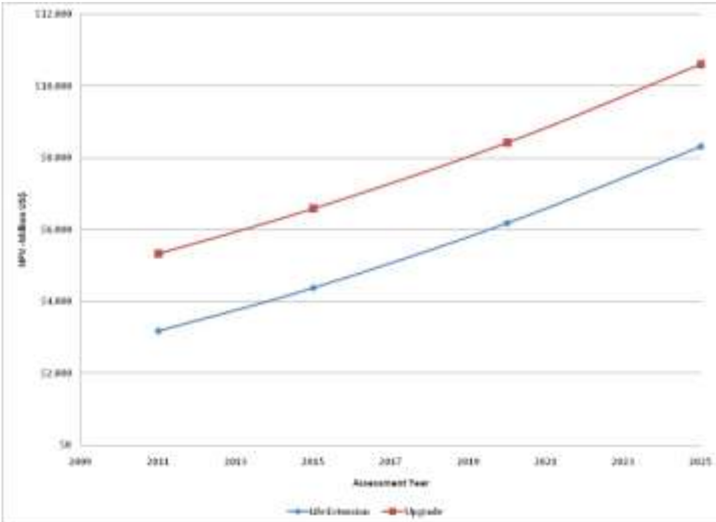
Further one can see that for Central America, a US$ 2 billion of investments yields US$ 3.2 billion in benefits.

6.1.3 Results at Other Reference Years

The above tables reflect the economic scenarios with a reference year of 2011 (current year). As we move forward to other reference years, the amount of economic rehabilitation will grow. Table 6.1 gives the economic rehabilitation values at 5-year increments for the next 15 years.

A review of the table also indicates that the scope of the market for rehabilitation is substantial in the two regions. The present value of the costs of undertaking the rehabilitation is currently estimated at more than US$4 billion for life extension and more than US$5 billion for upgrade. It should be pointed out, however, that this assumes that life extension and upgrades have not been carried out for any of the projects. For many projects this may have already been done which would significantly affect the market assessment. Further work could be done to identify which stations have been upgraded and when, so that a revised assessment could be compiled. Figure 6.1 shows a graphical representation of the variation of the NPV in the future assessment years.

Figure 6.1 Variation of NPV for Various Assessment Years.



6.2 Sensitivity Analysis

A sensitivity analysis was carried out to test the economic assessment in terms of the costs and benefit functions developed above. Three sensitivity cases were examined as follows:

- 20 % non-reliability of the units was assumed after 60 years (instead of 10%)
- 0.1%/yr turbine efficiency degradation was assumed (instead of 0.06%)
- A unit outage of 6 months was assumed (instead of 3 months) and 100% of potential energy lost was assumed (instead of 20%)

The results of this assessment are given in Table 6.2. Significant variations in the NPV can be seen for all cases indicating that some further investigations to refine these parameters may be warranted.

Table 6.2 Sensitivity Analysis of the Economic Rehabilitation Potential.

Sensitivity Case	Scenario	Region	PV of Benefits (MUS$)	PV of Costs (MUS$)	NPV (MUS$)	Levelized Cost (US$/MWh)	IRR %
Base Case	Life Extension	Africa	$5,415	$2,872	$2,543	$69.70	15.7%
		Central America	$2,251	$1,616	$635	$74.13	16.0%
		Total	**$7,666**	**$4,488**	**$3,178**	**$71.47**	**15.8%**
	Upgrade	Africa	$8,063	$3,901	$4,162	$84.32	17.0%
		Central America	$3,195	$2,029	$1,166	$92.42	16.8%
		Total	**$11,258**	**$5,930**	**$5,328**	**$87.66**	**16.9%**
20 % non-availability after 60 years instead of 10%	Life Extension	Africa	$12,314	$4,488	$7,826	$53.95	21.1%
		Central America	$5,891	$2,891	$3,000	$54.09	20.3%
		Total	**$18,205**	**$7,379**	**$10,826**	**$54.01**	**20.8%**
	Upgrade	Africa	$14,674	$5,432	$9,242	$63.22	20.5%
		Central America	$7,044	$3,722	$3,323	$68.19	18.9%
		Total	**$21,718**	**$9,154**	**$12,564**	**$65.30**	**19.9%**
0.1%/yr efficiency degradation instead of 0.06%	Life Extension	Africa	$7,249	$3,466	$3,783	$72.06	16.6%
		Central America	$3,387	$2,203	$1,184	$75.73	16.4%
		Total	**$10,635**	**$5,669**	**$4,967**	**$73.56**	**16.6%**
	Upgrade	Africa	$10,537	$4,628	$5,910	$83.32	17.9%
		Central America	$4,709	$2,810	$1,899	$87.82	17.7%
		Total	**$15,246**	**$7,437**	**$7,809**	**$85.15**	**17.8%**
Unit out for 6 months instead of 3 months & 100% of unit energy lost instead of 20%	Life Extension	Africa	$1,929	$1,602	$326	$86.86	11.5%
		Central America	$508	$293	$215	$60.23	17.3%
		Total	**$2,436**	**$1,895**	**$541**	**$76.47**	**13.8%**
	Upgrade	Africa	$6,217	$4,663	$1,555	$107.36	12.5%
		Central America	$2,032	$1,497	$535	$96.52	15.6%
		Total	**$8,249**	**$6,159**	**$2,090**	**$103.23**	**13.6%**

7 LESSONS DRAWN FROM REHABILITATION PROJECTS

This section provides a discussion of results of completed hydro plant rehabilitation projects. This is based on the information collected during the study to date on 9 rehabilitation projects (which was originally to be used to prepare case studies) and experience gained elsewhere working on hydro power plant rehabilitation projects. This section is prepared on an anonymous basis and does not tie specific information to specific projects. Information on lessons learned/pitfalls to avoid is also provided.

7.1 Background

This section discusses the rehabilitation projects that have been selected for the case studies. A sizeable number of completed rehabilitation projects were put forward as candidates for case studies. A number of meetings were held with Bank specialists and Bank staff engaged in ongoing internal discussions to finalize the selections. As the first step in the preparation of the case studies, a template which is referred to as the Case Study Information Sheet was prepared.

The main steps followed in the preparation of the case studies are as follows:

1. Collect detailed reports, worksheets and other documents for each project
2. As a desk study, complete the Case Study Information Sheet for each project to the extent possible

The intent was to meet with the owner and/or others directly involved with as many of the projects as possible to refine the data and understand the results of each project, especially any lessons learned over the course of the project. It would not have been possible to extract this content by just analyzing the available information. The information available to assess the projects generally comes from project reports and other information that was provided by the clients. As such this information has been treated as confidential and therefore specific references to projects are provided in an anonymous manner in the sections below.

The available information varied from project to project. Some case studies had good information while others were less well defined; however, all information was assessed in an effort to bring the maximum value to the study.

7.2 Case Study Content

The purpose of the case studies is to indentify key barriers and constraints to rehabilitation projects, as well as success factors. A better understanding of these factors will help in the design and preparation of projects, and provide insight into both owner/operator and public responsibilities. Specific issues are compared across case studies and aggregated into the synthesis report and guidance note. Table 7.1 provides an outline of the content of the case study questionnaire that was used to prepare the case study information abstracted from the available references.

Table 7.1 Outline of Case Study Content

1. Introduction	**7. Financing**
2. Description of Facility a) Original facility b) Rehabilitation project: expected/actual benefits, costs	**8. Hydrology** c) Technical issues during implementation d) Manufacturer conditions and restrictions e) Scheduling
3. Scoping of Rehabilitation Investment 1) Baseline assessment 2) Drivers for rehabilitation (incl. energy market, policy issues) 3) Options analysis to define selected rehabilitation project	**9. Technical** a) Technical issues during implementation b) Manufacturer conditions and restrictions c) Scheduling
4. Decision-Making 1) Economic analysis: expected and actual benefits and costs 2) Treatment of uncertainty/risk 3) Decision roles and responsibilities 4) Stakeholder engagement 5) Decision tools and approaches for options assessment and trade-offs	**10. Environmental and Social** a) Detailed assessment of rehabilitation/reoperation potential b) Integration in project design and implementation and issues during implementation c) Impact management d) Treatment of legacy issues
5. Institutions, Policies and Capacity – Public 1) Regulatory requirements and processes 2) Public policy constraints and barriers 3) Public-private coordination	**11. Ongoing O & M** a) Monitoring & ongoing maintenance b) Roles and responsibilities/Capacity c) Asset planning
6. Institutions, Policies and Capacity – Owner 1) Role of operator vs. owner vs equipment manufacturer 2) Organizational effectiveness (maintenance vs rehabilitation) **3)** Capacity	**12. Conclusion – Lessons Learned**

7.3 Case Study Projects

The case studies contain some sensitive economic data and are therefore not mentioned by name. The main drivers for the Case Study projects are as follows.

Project 1 – Main Project Drivers

- Increase reliability and safety of operation, reduce maintenance and forced outages and extend equipment life
- Improve turbine performance using modern state of the art technology and more efficient turbine runners to increase generation output
- Rehabilitate the controls, metering, protection, and data logging in the powerhouse and control room.

Project 2 – Main Project Drivers

- Increase energy and capacity at the facility with modern turbine runner designs
- Inspect existing equipment and replace or repair all worn or damaged components in order to extend the life of the units for the next 20 to 30 years
- Expansion with installation of an additional unit

Project 3 – Main Project Drivers

- Increase energy at the facility through the increase in plant capacity, recognizing that flow in the river often exceeded the capacity of the original facility.
- Upgrade of existing turbine and generator equipment including governors and turbine inlet valve with new generating units of similar configuration but significantly higher capacity of 20%
- Replacement of the powerhouse controls
- Installation of additional transformers to accommodate the increased power levels
- Major modification to civil works to accommodate the increased discharge capacity

Project 4 – Main Project Drivers

- Increase in revenue through added capacity that could utilize excess flow that was available for a significant portion of the year. There was also some added benefit to a modern turbine runner design with increased efficiency.

Project 5 – Main Project Drivers

- Provide urgently needed least-cost capacity additions to the system power generation capacity
- This was a project expansion and was not a classic rehabilitation project
- Increase the safety of the dam and associated infrastructure

Project 6 – Main Project Drivers

- Improvement of the reliability of the electric service and increase service coverage by rehabilitation, modernization and expansion of power generation, transmission, sub-transmission and distribution systems
- Purchase equipment necessary for sedimentation control

Project 7 – Main Project Drivers

- Expansion of a completed project in order to increase the generating capacity as part of the long-term plan for the development of hydroelectric resources

- It was justified as a least cost project in the expansion sequence but was not really a rehabilitation project given the relatively young age

Project 8 – Main Project Drivers

- Multiple hydroelectric facilities subject to larger than expected wear and tear of the generating units

Project 9 – Main Project Drivers

- The World Bank provided assistance in restructuring the power sector, with rehabilitation of the supply system a first priority
- Three major power stations were targeted for rehabilitation under the project
- The project includes rehabilitating hydropower plants and distribution and transmission systems to improve technical efficiency and the quality and reliability of supply

7.4 Case Studies Results

The details of the results of the assessment are given in Annex C. A summary of the Lessons Learned from these case studies is given in Section 9 – Conclusions of this report.

The lessons learned have been divided into technical, contractual and implementation, institutional and financial as well as one section on barriers and incentives.

On the technical side, a central issue is that one needs to have competent staff, experienced consultants and engagement with the technology providers in order to be on time, keep the budget and have a successful operation after the rehabilitation is complete.

One of the main lessons regarding contractual matters and Implementation is that risk management is essential. Risk management does not mean to pass all risks to suppliers and contractors, as this will drive costs. During implementation it is important to be aware that the project might change related to discoveries from dismantling units etc.

Institutional lessons are to gear up procurement capacity, preferably with support from experienced engineers to ensure that complex procurement might be expedited timely. On the financial side, flexible credit lines need to be in place to deal with findings during project implementation. Again this needs to be linked to engineering competencies to be navigated timely and successfully.

Traditional economic assessment may not consider risk for rehabilitation, upgrades or replacement schemes. However, in most cases risk-costs are an important factor in determining the need for interventions. The consequent cost of failure can be an important factor in assessing and justifying the rehabilitation of hydropower components.

A key consideration in rehabilitation is to economically optimize outage scheduling of the generating units without compromising system operational constraints. In most rehabilitation projects it is prudent to consider extension / expansion of existing hydropower capacity, as well as taking into consideration dam safety issues.

8 HYDRO REHABILITATION PROJECTS - BARRIERS AND INCENTIVES

8.1 Technical

8.1.1 Introduction to Failure Probability Concepts

In traditional maintenance practice no quantified consideration was given to risk of failure in order to determine the need for major maintenance involving replacement of parts or subcomponents. Similarly, capital expenditures, such as rehabilitation, upgrades or replacement schemes did not consider risks. This was traditionally left to judgment. However, in most cases risk-costs are an important factor in determining the need for interventions. In modern maintenance planning, risk considerations do play some role, albeit mostly in a simplistic and often qualitative manner and without least cost considerations.

Risk-costs and maintenance costs increase with advancing age, but if the capital investment in rehabilitation can be safely deferred, then the present value of that investment is reduced. It is the trade-off between reducing that present value by deferral, and increasing risk and its cost (and often maintenance and outage costs) by the same deferral, which will justify the extent of rehabilitation and its timing. Risk costs depend on the financial impact of having to repair a unit that has had a component failure plus the loss of generation coupled with the changes of the failure occurring as outlined in the section below.

Failure Rates for Hydropower Components

It is well established that the risk of failure(s) of hydropower components, as in other components, increases with time in a nonlinear manner. Failure analysis must consider the existence of different failure modes, each of which will contribute to or result in replacement of the component.

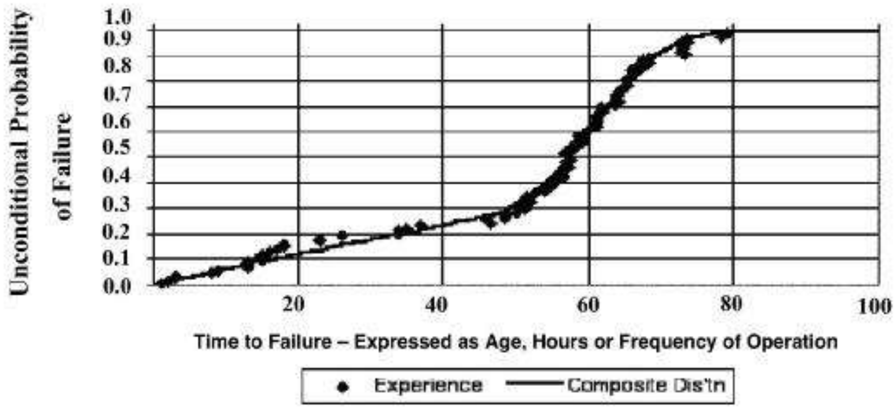
The combined effect of all failure modes over time is expressed through a survival or retirement curve, otherwise known as a failure-probability curve, shown in Figure 8.1.

Condition Assessment and Representative Age

Condition assessments of equipment systems and components are an important part of life cycle analysis. Fortunately, most utilities nowadays undertake such detailed condition assessments. The economic risk-based methodology utilizes this information to establish a representative (as opposed to physical) age of the component. This may be achieved directly from condition information (REMR[6] method), or through the use of Health Indexing methods. It is the representative age that describes the component in terms of its operating environment, maintenance history and manufacturing quality. This age is therefore the starting age for life cycle management analysis.

[6] Repair Evaluation Maintenance Rehabilitation, http://www.wes.army.mil/REMR/

Figure 8.1 Typical Failure-Probability Curve.



Consequence Cost

Risk is the product of probability of failure and the consequence cost of that failure. Consequence cost is therefore as important a factor as the failure probability itself. Consequence cost comprises all direct and indirect costs (engineering assessment, planning, administration and project management, procurement if required, material cost, labor cost and damage to other components), as well as the cost associated with loss of production (downtime).

The cost of lost production may be broken down by the duration of outage and the unit rate of that outage. A typical example of consequential costs could include the loss associated with an unplanned outage due to a failure of a major component such as a runner. A 10 MW unit operating at 50% annual plant factor forced out of operation for a year, which could be realistic if a new runner had to be manufactured, could result in a loss of revenue of US$4.3 million based on an energy value of US$100/MWh. Comparing this to the cost of a life extension involving a replacement runner and a generator rewind which is close to US$6 million, it can be seen that consequential costs become very significant for older equipment where the probability of failure is high.

Unexpected outages might also lead to larger blackouts and have wider systemic consequences in power systems operating close to their capacity.

Economic Analysis

The risk, maintenance, capital cost and benefits cost streams themselves do not address the question of whether or not to rehabilitate, on what basis this is warranted (benefits and savings), what the best rehabilitation measure is and at what point in time it should be implemented. These questions must be addressed through economic analysis. For this a “do nothing” case is assumed. Risk-costs are calculated annually from conditional failure-probabilities and consequence cost information and are an increasing cost series. The use of a discount rate permits the NPV of this cost series to be determined. The NPV then represents the to-day cost of operating the component until its retirement, using maintenance and repair works if failure occurs.

When rehabilitation is introduced, future failure probabilities are reduced from rejuvenation. By calculating the NPV for each potential year of intervention and plotting these against time, the minimum NPV cost can be determined, representing the optimum intervention timing. At that point the reduction in overall NPV cost from deferral of capital investment is ultimately offset by the increasing NPV of risk-costs.

8.1.2 Other Analytical Approaches

As shown, individual elements of the methodology can be captured by a spreadsheet approach. However, the mathematical and statistical calculations of the intricate aspects of the methodology make this approach unsuitable for a more integrated analysis. In addition, data collection and manipulation is cumbersome.

One example of a designed program that is commercially available is the HydroVantage model, developed by Hatch. Even though models like these are readily available, many utilities prefer to develop their own from scratch. Even though this allows more customization and modeling, the results might be better with a transparent, fast and versatile decision support tool that incorporates all aspects of the risk-based methodology for assessing rehabilitation in a detailed component-specific manner.

8.1.3 Rehabilitation Outage Impacts on Meeting Load

A key consideration in rehabilitation is to economically optimize outage scheduling of the generating units without compromising system operational constraints. This normally should be done in a study with computer simulations / optimizations to:

- Demonstrate that the model can provide long-term water usage pattern consistent with historical operations.
- Evaluate the indirect costs as well as economic benefits of unit outage schedules.

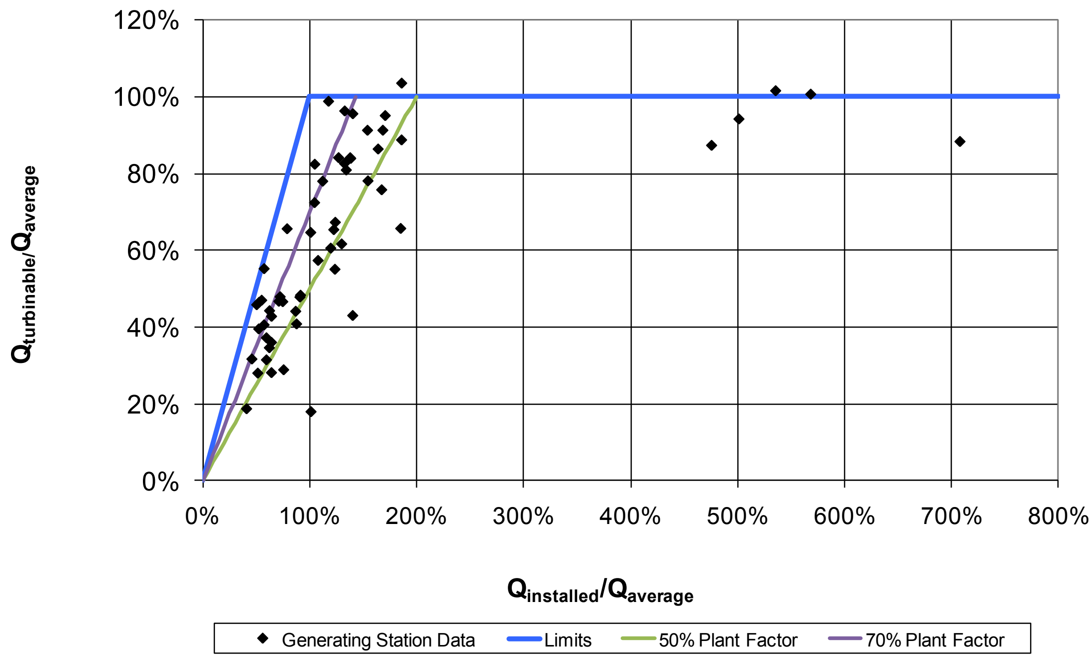
Detailed simulations of the generation over a one year period are required without the outage plan in place to define the base case. Comparison simulations should be undertaken with alternative expected outage plans. These comparison cases enabled the calculation of the indirect costs of the plan. Results include:

- Major outage alternatives economic evaluation
- Least cost plan including timing for the rehabilitation outage.

8.1.4 Project Expansions

The potential for the expansion of hydropower projects cannot be based solely on age. It is essential to have an indication of the current discharge capacity relative to the discharge in the river so that the untapped potential can be determined. In the case of a single hydro station if it found that the station spills regularly, this is a clear indication of a less than optimal capacity. In the case of a portfolio of stations, a method ranking the stations can be a useful tool. Figure 8.2 gives such a method of ranking a portfolio of generating stations in Canada. This figure shows the ratio of the captured ("turbinable") discharge to the average river discharge ($Q_{turbinable}/Q_{average}$) for a given ratio of power ("installed") discharge capacity to average river flow ($Q_{installed}/Q_{average}$). Large values of $Q_{installed}/Q_{average}$ are indicative of stations constructed for peaking operations while small values are indicative of stations which might, for economic reasons, lack of good design data, etc, warrant an expansion. The presence of storage could also be factored into this assessment to determine its impact but for an initial examination of the potential for expansion this figure could be suitable for ranking of projects for further investigations.

Figure 8.2 Assessment of Station Expansion or Redevelopment Potential



Also indicated on this chart are plant factor lines for 50% and 70% respectively. Plant factor is estimated by dividing $Q_{turbinable}/Q_{average}$ by $Q_{installed}/Q_{average}$. These lines can be used to identify hydroelectric generating stations in a fleet of stations which have plant factors which would be attractive for expansion. The average plant factor for all the hydro stations in Africa and Central America is approximately 50% and if this were used as a target for development then this figure can be used to identify stations with some potential for expansion. For example all stations falling to the left of the 70% plant factor line would have factors greater than 70% and would have a good potential for generating additional energy if the installed capacity were increased. Stations falling between the 50% and 70% line would have a lower potential for expansion. Further examination of this potential would have to be done by visiting the sites and examining the arrangement to see if expansion is likely to be feasible and economically attractive.

8.1.5 Dam Safety Driven Rehabilitation

Before considering if rehabilitation can be economically justified it would be prudent to examine the safety aspects of the water retaining and other civil structures to ensure that they can be expected to have a life which can justify the capital investment involved in the rehabilitation. Safety driven rehabilitation of dams and hydropower installations can strain owners' technical, financial and engineering resources due to deterioration of the facilities or a change in design standards. The ability to identify dams and associated generating stations with the greatest safety risk will help focus the attention of owners and regulators — enabling the better allocation of limited resources and enhancing overall safety.

If one needs to upgrade the dam and hydraulic structures of any given hydro station this could be a beneficial time to revise/upgrade/rehabilitate the hydropower station as well. Dam structure upgrades often involve lower or empty reservoir levels which reduce the impact of rehabilitation.

Initially implemented by the Ontario Ministry of Natural Resources (MNR) by applying the United States Bureau of Reclamation (USBR) “Risk Based Profiling (RBPS) to a series of dams in the province, Hatch developed a Dam Safety Risk Screening Tool (RST). The primary goal of the RST is to support programmatic decision-making for owners with a portfolio of dams. The tool offers effective means for prioritization within a portfolio by separating those dams requiring urgent attention from those that do not. As such, RST is intended to help screen the entire portfolio and rank all dams for further evaluation. RST is a set of linked spreadsheets with capabilities to:

- Assess the probability and consequences of failure for each component of a dam under a broad range of potential failure modes
- Present each risk assessment independently to identify potentially critical dam components and failure modes
- Consolidate the consequences to assess the total risk tolerability of the dam in its existing condition
- Address absolute rather than relative risk
- Quantify the probable error in the assessed screening risk
- Visualize results and compare with widely accepted risk guidelines
- Create RST-generated charts for probability vs. consequence of (L) loss-of-life and (R) economic risks.

The importance of such a tool cannot be overstated when considering the realities and complexities of dam-safety problems. The regulators of dam safety can now allow dam owners to take advantage of RST to identify the structures within their portfolios that require urgent attention.

8.2 Financial

The ability to arrange financing for a rehabilitation project, as for any complex project, depends on the level of risk judged to be associated with the project (both project risk and commercial market risk), the communication of the project to potential funders and the risk/reward profile of the potential funders. In the extreme case, funding could be withheld entirely, and in the best case scenario the terms and conditions of funding will be dependent on perceived risk. Thus two key factors that could be either barriers or incentives are the quality of information on the project to reduce uncertainty (and thus the risks associated with uncertainty) and the allocation of the remaining risks to the party that can best manage the risk. Motivated investors are those that have full disclosure, a high level of project and market certainty and a risk management strategy in place.

Some of the key aspects of a hydro plant rehabilitation project that can either be barriers to financing or incentives, are listed below. Reduction of uncertainty associated with these key factors reduces the assessed level of risk for the project and can increase access to financing as well as improve the terms and conditions that can be negotiated.

• Good hydrology information. It is now becoming evident that hydrology data simply cannot be projected; it needs to be adjusted for increasing demands on water resources from agriculture, industry and human consumption, as well as the impact of climate change. Application of a probability assessment on hydrology, taking account of trends and cycles, must be part of the assessment. The result could be changes in design to optimize plant value under the best estimate of future hydrology and in particular the water likely to be available for power generation.

- Thorough geotechnical information where rehabilitation or expansion necessitates major new civil works. It is noted that hydro plant rehabilitation generally does not encounter geotechnical uncertainty when it is mainly electromechanical, as is the focus in much of this report.

- A Power Purchase Agreement (PPA) with a credit-worthy off taker. Financing is rarely available today for merchant hydro plants.

- Environmental and socioeconomic impact assessment studies and licensing approvals as a consequence of these studies. Expansions or even rehabilitations can trigger the application of today's much higher standards and to the extent the approvals processes can be completed or, at a minimum, fully scoped, a major source of uncertainty can be removed or reduced.

- Optimization based on preliminary design to a stage to enable project scope to be set and agreed to with key stakeholders.

- Preliminary engineering design and risk adjusted cost estimates.

- A competitive bidding process that is open, transparent and fair resulting in the best price/best terms/best delivery team and the controls to ensure that what was promised is delivered and that performance guarantees are in place and adhered to during the early operation of the plant.

- A thorough risk assessment with risks quantified and mitigation measures identified and risk allocated to those parties best able to manage that risk.

With respect to the last point in the list above, a *risk register* is a convenient way to summarize the findings of a risk review. For each risk area the register should indicate the relevant factors and indicate the risk mitigation measures that are planned and how the project agreements would allocate the residual risks to the stakeholders that are most capable of carrying these risks. The format of a typical risk register is shown in Figure 8.1 below.

In a risk review workshop attended by primary stakeholders, the significant risk areas for the rehabilitation project are identified and form the rows of the risk register. These could include hydrology, regulatory/permitting, land access, transmission, geology, equipment procurement, equipment performance, material supply, weather impacts, labor factors, design issues, contractor performance, community support, the market and price for the output, replacement power, etc. The columns of the register provide information on risk description, trigger, impact, likelihood, consequence risk rating, risk management strategies/measures/controls, residual risk and possible further actions for each of the risk areas. Diligent work to record and mitigate project risks using the risk register as a tool can significantly reduce barriers to financing of a hydro plant rehabilitation project.

Table 8.1 Example of one component of a risk register.

No.	Project	Risk Area	Risk Description	Trigger	Impact	Inherent Risk			Existing Risk Strategies/ Controls	Effectiveness	Residual Risk			Further Action/Risk Treatments
						Likelihood	Consequence	Risk Rating			Likelihood	Consequence	Risk Rating	
Resource														
R1	All	Hydrology (Climate Change)	Hydropower project planned for country / region with uncertain and variable rainfall / glacier melting. Risk that pattern of rainfall / glacier melt is significantly altered by climate change.	Unexpected and/or pro-longed drought Incorrect or changing hydrological data or misinterpretation of hydrological data Climate change impacts availability and variability of resources	Unexpected low or high energy yields Inability to generate power over the project life cycle Insufficient revenues and failure to achieve projected project returns Exposed to spot market prices Damaged reputation with off-taker	Rare	Catastrophic	HIGH	Hydrological data gathered over past 50 years Energy contracting strategy to limit PPA's to 95% confidence, based on extensive historical data (50 years) to decrease spot market exposure Market prices are high and expected to be maintained or increase over the short term	80%-90%	Rare	Insignificant	LOW	Inability to secure PPAs to 95% confidence levels will need to develop thermal plant for energy back up assurance

In structuring and arranging a hydro plant rehabilitation project, it is essential for the project sponsor (most often a government-owned utility) to ensure that the negotiated contract maintains the risk transfer to the private sector that had been set out in the risk assessment and project feasibility study. This requires a detailed formal contract that protects the project sponsor and effectively holds the delivery team accountable. Performance must be guaranteed by financial instruments sufficient to enable project completion in the event of delivery team or project failure. Hence, due diligence on the technical and financial capacity of the winning team is essential. Procurement processes where the bidding consortium is also responsible for arranging full project financing, and payment by the sponsor is based on meeting the terms of the contract or the performance requirements over the concession period, can be the most effective arrangements to protect sponsor interests. Such cases enable the sponsor to ensure the team carrying out the project is paid only on successful performance, thereby keeping risk with the winning team. Lenders to the winning team provide an extra level of scrutiny in ensuring the integrity of bids and the minimization of risk being assumed by the team.

In Africa, and to a lesser but still significant extent in Central America, many of the existing hydro plants are owned by the national government through its national electric utility. Very frequently this means that there is limited or no funding available from the government owner for rehabilitation projects. The Public Private Partnership (PPP) approach has been used in financing and delivering infrastructure projects in some locations. This approach can be more difficult for a rehabilitation project than for a Greenfield project in that the investment in the rehabilitation would become an integral part of a government owned asset. It is expected that in many cases the government would not be willing to privatize the existing hydropower services. In this case, a possible approach would be to pledge an appropriate portion of the rehabilitated plant's output to the private sector investor on a long-term basis in return for the investment. This method could prove particularly attractive when the rehabilitation would either allow the plant to return to operation or increase the output and reliability of supply to such an extent that both the government and the private sector investor would benefit. Private sector mining companies needing access to incremental electricity supplies for large new mining/mineral processing projects would be an example of possible investors under this model. In this case, the private sector partner might also have responsibility for operation and maintenance of the entire plant over the concession period to ensure that reliability is maintained, and returned in good condition to the government utility at the end of the concession period.

Financial risk coverage instruments are available from the World Bank and IFC and may be necessary in countries without robust financial institutions, power distribution utilities that lack adequate credit ratings to satisfy project investors or constitute political risk where investors may need supplementary guarantees from international financial institutions.

8.3 Institutional, Environmental and Social

8.3.1 Opportunities and Incentives

A rehabilitation project provides opportunities for capacity building, training, environmental rehabilitation and compensation, and the opportunity to develop social programs aimed at affected populations. These are often relatively low cost and effective programs that provide for long term benefits to the communities and the environment. Funds for this type of project can be included in financing from various sources such as multilateral institutions and commercial banks. In Brazil for example, the national economic development bank (BNDES) will loan additional funds to be allocated to environmental or social improvement programs as an incentive for obtaining future financing at preferential rates. The amount is equivalent to 1-2% of the total project financing and cannot be used to meet the environmental regulatory requirements of the project and must meet certain conditions, such as generate local employment. These funds are available at lower rates and do not necessarily have to be spent on programs directly related to the project but can be used to alleviate legacy issues or address any other capacity, education, environmental or social needs.

A rehabilitation project also offers the opportunity to address any unforeseen environmental and social impacts due to the project that resulted from constructing the original plant.

8.3.2 Weak Institutional Capacity

As many of the existing hydro plants in Africa and to a lesser extent in South America, are owned by government utilities, the availability of skilled resources within the government agencies and authorities to manage project implementation and to shepherd projects through the approval stages is likely to be a barrier in some cases. Weak institutional capacity of relevant agencies combined with civil unrest, war and disaster has led to significant neglect of infrastructure maintenance in many African countries. However, differences in governance, private sector involvement, level of economic activity, conditions of peace and stability, and electricity demand, factors which are often inter-related, will significantly affect infrastructure spending among countries and a range of institutional capacity and infrastructure maintenance needs exist throughout the continent.

Typical institutional weaknesses that can hinder infrastructure project implementation include:

- Lack of institutional coordination.
- Lack of or weak communication mechanisms among different administration levels.
- Centralization of decision-making and lack, or little flow, of information resulting in decisions not reflecting actual needs.

8.3.3 Weak Private Sector

In many countries in Africa, the private sector is weak (and/or few private players exist) because of bureaucratic and policy obstacles. The cost of doing business in Africa can be 20 to 40% above other regions due to high regulatory costs, unsecured land property rights, unfair competition from well-connected companies, ineffective judiciary systems, policy uncertainty, and corruption.

8.3.4 Regulatory Changes

On the environmental side, in many countries approval processes and approval criteria may have changed significantly since the project was first constructed. Depending on the regulations that apply this could make it more difficult for a rehab project to receive approval even if the environmental impacts could be shown to be minimal or non-existent.

Expansions or even rehabilitations can trigger the application of today's much higher standards and to the extent the approvals processes can be completed or, at a minimum, fully scoped, a major source of uncertainty can be removed or reduced. Depending on the source of funding one will have to apply the World Bank Safeguards[7], the Equator Principles[8], IFC's performance standards[9] etc. to evaluate impacts and devise potential mitigation/adaptation measures. These may apply for expansions or upgrades alike depending on their separate criteria.

8.3.5 Changes in Watershed

Significant changes in watersheds upstream of hydro works can happen over time, especially with the long life cycles of most infrastructure. For example, in countries where economic development has encouraged the expansion of agriculture, deforestation to make place for crop land has led to increased sediment transport in rivers. This can lead to an increase in the sedimentation rate of reservoirs, decreasing live storage and affecting equipment and generation. Dredging reservoirs regularly can increase operating costs significantly and add to the complexity of operating a power plant with limited resources.

The settling of population and communities around reservoir shorelines or downstream of a hydropower plant along the river may constrain rehabilitation projects that wish to realign the management of water resources to meet market opportunities or demand, limiting the amount of peaking operations and water level fluctuation that the river system can absorb without significant environmental and social effects. Public support for this type of project can prove more difficult if legacy issues are already present.

[7] www.worldbank.org/safeguards

[8] http://www.equator-principles.com/

[9] www.ifc.org/performancestandards

9 CONCLUSIONS

9.1 Hydropower Assets Tool

- A spreadsheet-based hydropower assets tool (HAT) was applied to two regional inventories of hydroelectric generating station data and a summary was prepared outlining stations and units assessed to be in good, fair and poor condition. The assessments carried out by the HAT are based on the age of the assets measured from the initial date of commissioning. The trigger ages used for this assessment may not reflect the particular conditions in all regions of the world and should be verified with actual experience.
- By applying the tool to the two regions, 120 potential projects were located in two limited regions; continental Africa and Central America and Mexico.
- In Africa, a total of 73 plants were indicated to have economic rehabilitation potential. Of these 25 are plants with a capacity of less than 50 MW but more than 10 MW, 35 plants between 51 and 250 MW and 13 plants of greater than 250 MW.
- In Central America a total of 47 plants were identified. Seventeen were plants under 50 MW but over 10 MW, 22 plants between 51 and 250 MW and 8 plants over 250 MW.

9.2 Market Analysis of Hydropower Rehabilitation

- Building on the results from the HAT, a spreadsheet model was developed which applied to the two regional inventories, was used to arrive at an assessment of the potential market for hydropower rehabilitation. Rehabilitation being considered in this assessment is concerned only with major electrical and mechanical equipment and not the civil aspects of the dams, waterways, station, etc. The model was based on typical benefits to be gained from rehabilitation in terms of efficiency, capacity and availability. A life extension scenario involving like-for-like replacement of the turbine runner and an upgrade scenario involving modern day improvements to the runner were examined.
- The application of the economic analysis to the inventories gave an order of magnitude estimate of the value of the cost for economic rehabilitation projects in 2011 to be in excess of US$ 4 billion for the life extension scenario and greater than US$ 5 billion for the upgrade scenario. The total net present value of benefits is estimated at US$ 3 billion and US$ 5 billion respectively for the two scenarios. The net present values of benefits are estimated to increase to US$ 8 and US$ 10 billion, respectively, by 2025 assuming that no rehabilitation is undertaken in the intervening time.
- If the rehabilitation is deferred, the net benefits and IRR increase as indicated above however one can expect availability and reliability of the power production to drop. Thus, from a system capability perspective it is quite likely that there is a shortfall in the energy production and the risks and costs of inaction should be considered in terms of alternatives which could be used to meet the energy requirements. The current analysis uses typical energy values that one might expect but it does not go into the detail of examining alternative sources of supply which is a project specific study. Another consideration is the uncertainty of financing which could exist if the project is postponed. This analysis does, however, provide the scale of the economics of rehabilitation which was the objective of this part of the study.

- This market analysis for hydropower plant rehabilitation has two limitations: (i) there is no consideration of the actual condition of the individual units; and (ii) there is no consideration if the units have already been rehabilitated as this information was not available.

9.3 Lessons Learned from Rehabilitation Case Studies

Several historical rehabilitation and extension projects were reviewed with the objective of identifying "Lessons Learned" to assist in the future planning and execution of hydropower rehabilitation projects. Nine case studies that were reviewed indicated the following main Lessons Learned. The lessons have been used to generate a generic ORAF (Operational Risk Assessment Framework) that is attached in appendix D. Even though some of these factors seem obvious in retrospect, they are nonetheless important and might easily be missed related to the complex issues of a rehabilitation project.

9.3.1 Technical

- Turbine and generator efficiency tests to verify pre- and post- equipment performance are essential as units may be performing worse than originally anticipated.
- Where possible, testing of a single unit upgrade performance prior to undertaking the remainder of the unit upgrades is recommended as this can lead to changes in the designs for subsequent units to maximize benefits. Homologous testing and CFD can be considered.
- The life extension option which only recovers historical efficiency and availability degradation may be significantly less economic than the upgrade option involving installation of more efficient and higher capacity equipment associated with modern technology.
- Owners / operators of the station should be involved with the manufacturers to the maximum extent possible in both the design and implementation of the rehabilitation in order to increase knowledge transfer, the performance of the unit and reduce costs.
- Well defined and clearly limited rehabilitation objectives and specifications will avoid conflicts on scope of rehabilitation work during the project execution phase.
- Issues such as sediment transport and its effect on equipment should not be underestimated or treated lightly in the design stage.

9.3.2 Contractual / Implementation

- It is not beneficial from a financial or project implementation perspective to pass all risks associated with uncertainties on equipment condition to the contractor during the bid/proposal stage.
- Careful management of materials, workers, equipment and logistics / work schedules is essential to minimizing problems at site and preventing or minimizing site schedule delays and cost overruns.
- Hydropower rehabilitation projects are susceptible to changes and timely mid-term reviews are important to update methodologies and work schedules.
- While extension / expansion projects can be impacted by low load growth, one of the advantages of rehabilitation projects is that they are unlikely to suffer the same effect as the increment in output is smaller.

- Attention should be paid to the risks related to possible delays caused by the project approvals, as well as delays during preparation and holding of procurement tender.
- A primary task during the project implementation is to identify deviations from what was planned and to initiate activities to ensure that appropriate approvals are obtained prior to proceeding with any deviations.

9.3.3 Institutional / Financial

- Hydropower projects in general and rehabilitation in particular has complex procurement procedures. For clients that have poor procurement capacity and experience with these types of projects, their capacity should be improved prior to commencement of the works in order to avoid delays caused by poor procurement decisions.
- The project can provide workers with excellent training through close cooperation with the contractors. Furthermore, early cooperation with local authorities might build required competencies locally that reduce the costs and complications of importing workers.
- Due to the restricted time available for completion of the rehabilitation, a focus on team work and team building are imperative to successful project implementation.
- Rehabilitation projects require more flexible financial solutions to reflect findings during project implementation. This requires complex financing arrangements that need financial and engineering expertise to be navigated timely and successfully.
- In most successful projects, the affected stakeholders have been involved at an early stage as their experiences and requirements can affect the project, even for smaller rehabilitation projects.
- Review of project cost estimates by an independent consultant helps to ensure that the estimates are reasonable and up to date and increases the accuracy, minimizing cost overruns or under runs.
- Technical and engineering skills, strong project ownership and commitment to results as well as accountability on the side of the project owner are critical success factors.

9.3.4 Rehabilitation Projects - Barriers and Incentives

- Traditional economic assessment may not consider risk for rehabilitation, upgrades or replacement schemes. However, in most cases risk-costs are an important factor in determining the need for interventions. Risk of failure(s) of hydropower components increases with time in a nonlinear manner as a failure-probability curve. The consequent cost of failure can be an important factor in assessing and justifying the rehabilitation of hydropower components.
- A key consideration in rehabilitation is to economically optimize outage scheduling of the generating units without compromising system operational constraints.
- Extension / expansion of existing hydropower projects require a detailed examination of the hydrology, power demand and civil costs to assess a project's overall economic value. The current study does not deal with extensions / expansions in any material way.
- A rehabilitation project allows for non-structural optimization and adaptation to changes in the natural hydrology, re-optimization of cascade releases, updating operational rules etc.
- It is prudent to examine the safety aspects of the water retaining and other civil structures to ensure that they can be expected to have a life which can justify the capital investment involved in the rehabilitation.
- The ability to arrange financing for a rehabilitation project depends on the level of risk judged to be associated with the project, the communication of the project to potential funders and the risk appetite of the potential funders that express interest in the project.
- The length of time required to complete IFI funding arrangements for investment in hydro rehabilitation projects and the terms and conditions of such funding has been seen by some owners as a limitation on the attractiveness of this funding.
- As many of the existing hydro plants are owned by government utilities the availability of skilled resources to shepherd projects through the approval stages and to manage project implementation is likely to be a barrier in some cases.

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ANNEXES

Annex A

– Hydropower Asset Tool (HAT)

A.1 Sample Applications

A sample output from the Condition Assessment sheet is provided in Table A.1. It can be seen that for this sample, there are 5 plants that are rated as Poor on one or more plant level components and thus are indicated to require rehabilitation. Similarly there are 3 plants with individual units that have one or more components rated in Poor condition thus requiring rehabilitation.

Table A.1 – Sample Output from the Condition Assessment Screening Spreadsheet

Plant Data							Opportunities				Condition Assessment						
Country	Plant	Unit	Unit Type	MW	Year	Status	Reoperation Recommendation (NHI Study)	Turbine Upgrade	Total # of Units	Generator Upgrade	Turbine	Generator & Transformer	Switchgear, auxiliary electrical, control systems	Mechanical: Gates, valves, cranes	Stn DC Electrical Batteries	Dam & Civil, Canals, Tunnels, Reservoirs	Powerhouse & Spillway, Penstocks, Roads, Bridges
MOROCCO	AFOURER-1	Stn		93.6	1955	OPR											
		1	FRANCIS/V	46.8	1955	OPR		Y	2	Y							
		2	FRANCIS/V	46.8	1955	OPR		Y	2	Y							
GHANA	AKOSOMBO	Stn		975	1965	OPR											
		1	FRANCIS	158	1965	OPR		Y	6	Y							
		2	FRANCIS	158	1965	OPR		Y	6	Y							
		3	FRANCIS	170	1966	OPR		Y	6	Y							
		4	FRANCIS	158	1966	OPR		Y	6	Y							
		5	FRANCIS	165.5	1971	OPR		Y	6	Y							
		6	FRANCIS	165.5	1971	OPR		Y	6	Y							
MOROCCO	AL MASSIRA	Stn		139.062	1980	OPR											
		1	FRANCIS	69	1980	OPR		N	3	N							
		2	FRANCIS	69	1980	OPR		N	3	N							
		3		1.062	1980	OPR		N/A	3	N							
MOROCCO	AL WAHDA	Stn		240	1997	OPR											
		1	FRANCIS/V	80	1997	OPR		N	3	N							
		2	FRANCIS/V	80	1997	OPR		N	3	N							
		3	FRANCIS/V	80	1998	OPR		N	3	N							
MOROCCO	ALLAL EL FASSI	Stn		240	1994	OPR											
		1	FRANCIS	80	1994	OPR		N	3	N							
		2	FRANCIS	80	1994	OPR		N	3	N							
		3	FRANCIS	80	1994	OPR		N	3	N							
MOROCCO	AMOUGGUEZ (HASSAN)	Stn		65.4	1987	OPR											
		1	FRANCIS	65.4	1987	OPR		N	1	N							
MADAGASCAR	ANDEKALEKA	Stn		58	1982	OPR											
		1	FRANCIS/V	29	1982	OPR		N	2	N							
		2	FRANCIS/V	29	1982	OPR		N	2	N							
EGYPT	ASWAN	Stn		550	1960	OPR											
		1	KAPLAN	40	1960	OPR		Y	11	Y							
		2	KAPLAN	40	1960	OPR		Y	11	Y							
		3	KAPLAN	40	1960	OPR		Y	11	Y							
		4	KAPLAN	40	1960	OPR		Y	11	Y							
		5	KAPLAN	40	1960	OPR		Y	11	Y							
		6	KAPLAN	40	1960	OPR		Y	11	Y							
		7	KAPLAN	40	1960	OPR		Y	11	Y							
		8	KAPLAN	67.5	1985	OPR		N	11	N							
		9	KAPLAN	67.5	1985	OPR		N	11	N							
		10	KAPLAN	67.5	1986	OPR		N	11	N							
		11	KAPLAN	67.5	1986	OPR		N	11	N							

Annex B

– Economic Assessment Model

B.1 Purpose

The purpose of the Economic Assessment Model is to provide a simple tool for analyzing the potential economic attractiveness of rehabilitation scenarios based on information that is readily available in the UDI World Electric Power Plants Data Base (WEPP). This data base is published by Platts, a division of The McGraw Hill Companies, Inc. The WEPP data base is a comprehensive, global inventory of electric power generating units. It contains ownership, location, and engineering design data for power plants of all sizes and technologies operated by regulated utilities, private power companies, and industrial or commercial auto-producers in every country in the world. The model is not intended to precisely model details of any particular hydropower rehabilitation project. Rather, it is intended to define the order of magnitude of the potential business opportunities which exist in the fleet of generating station in the African and Central America regions of the world.

The major limitations of this approach are that there is no consideration of the actual condition of the individual units and there is no indication if the unit may have already been rehabilitated.

B.2 Structure and Description of the Model

The Economic Assessment Model is an Excel-based spreadsheet containing several connected worksheets. Section 3 presents a sequential list of these worksheets and a description of their function.

B.2 Worksheet Descriptions

Worksheets 1 and 2 provide basic input to the model, Worksheets 3 to 5 provide the assessment for the Life Extension Scenario and Worksheets 6 to 8 provide the assessment for the Upgrade Scenario.

The benefits of a Life Extension Scenario are limited to rehabilitating the turbine to close to the original equipment specification. A clear limit on life extension is that it does not take advantage of changes in turbine technology but seeks only to extend the operation of the units with more or less the same output that was inherent in its original equipment.

The benefits of an Upgrade Scenario are not limited to returning the turbine to close to the original equipment specification. Upgrades take advantage of changes in technology for both the turbine and generator.

B.2.1 Worksheet 1 – Input Parameters

The input parameters are broken down into the Economic Data, Scenario 1 - Life Extension Data, Scenario 2 – Upgrade Data, Reference Cost Data and IRR Calculation Flag. The parameters under each of these headings are described in more detail in the table given below.

Worksheet 1 – General Information

Economic Data

Discount Rate	- Net (of inflation) discount rate
Maximum Service Life of Rehab	- Period over which benefits will accrue in years
Reference Year of Analysis	- Year to consider as being the current year in analysis
Energy Value	- Energy value in US$/MWh
Capacity Value	- Capacity value in US$/(KW-month)

Scenario 1 - Life Extension Data

Turbine Efficiency Gain (Technology)	- Efficiency gain in %/year of age (0 in this scenario)
Turbine Efficiency Recovery (Degradation)	- Efficiency recovery in %/year of age
Turbine Capacity Recovery (Degradation)	- Turbine capacity recovery in %/year of age
Turbine Capacity Gain (Technology)	- Capacity gain in %/year of age (0 in this scenario)
Generator Efficiency Gain (Technology)	- Efficiency gain in %/year of age
Generator Capacity Gain (Technology)	- Capacity gain in % depending on commissioning date
Availability Recovery	- Δ Availability in %=(Age / B)^x, B and x are constants
Life Extension Cost	- % of reference cost from Figure 5.2

Scenario 2 – Upgrade Data

Turbine Efficiency Gain (Technology)	- Efficiency gain in %/year of age

Turbine Efficiency Recovery (Degradation)	**- Efficiency recovery in %/year of age**
Turbine Capacity Recovery (Degradation)	**- Turbine capacity recovery in %/year of age**
Turbine Capacity Gain (Technology)	**- Capacity gain in %/year of age**
Generator Efficiency Gain (Technology)	**- Efficiency gain in %/year of age**
Generator Capacity Gain (Technology)	**- Capacity gain in % depending on commissioning date**
Availability Recovery	**- Δ Availability in %=(Age / B)^{x} where B and x are constants**
Life Extension Cost	**- % of reference cost from Figure 5.2**

Reference Cost Data

Capital Cost (MUS$)	**- Cost = A * Installed Capacity ^{B}, A and B are constants**
for Capacity <10MW	**- A=0.3666 B=1.3382**
for Capacity >=10MW	**- A=2.2091 B=0.5942**
Unit Outage	**- 3 months to undertake rehabilitation**
Lost Production Factor	**- Taken as 20% of potential losses except for single unit P/H**

IRR Calculation Flag

Flag	**- Used to set up for calculations of IRR**

B.2.2 Worksheet 2 – Plant Factor Information

Plant factor is defined as the average energy in MW continuous divided by the Installed Capacity in MW. This was obtained for each country in the two regions but unfortunately these factors were not available for each plant.

Worksheet 2 - Plant Factor Information by Country

Country	Energy GWh	Energy MW	Capacity MW	Plant Factor
Algeria	283.0	32.2	191.6	16.8%
Angola	3842.0	437.4	741.4	59.0%

B.2.3 Worksheets 3 and 6 – Typical Benefits for Scenarios 1 and 2

The typical benefits were developed and summarized on the basis of Technology Gain which was applied in terms of the year of commissioning and Degradation recovery which was applied on the basis of the age of the equipment. This separation was necessary since the model was applied to a reference year of 2011 plus other reference years going forward into the future to see how the total market for rehabilitation could change assuming that rehabilitation was not carried out.

Worksheets 3 & 6 - Typical Benefits from Life Extension and Upgrade

Technology Gain				Degradation Recovery			
Commission Date	Net Efficiency Gain	Net Capacity Gain	Net Availability Gain	Age	Net Efficiency Gain	Net Capacity Gain	Net Availability Gain
2010	0.00%	0.0%	0.00%	0	0.00%	0.00%	0.00%
2000	0.16%	0.0%	0.00%	10	0.60%	0.60%	0.27%
1990	0.31%	0.0%	0.00%	20	0.84%	0.84%	1.08%
1980	0.47%	0.0%	0.00%	30	1.26%	1.26%	2.46%
1970	0.63%	0.0%	0.00%	40	1.68%	1.68%	4.40%
1960	0.78%	0.0%	0.00%	50	2.1%	2.10%	6.91%

B.2.4 Worksheet 4 and 7 – Economic Assessment for Scenarios 1 and 2

The economic assessment worksheet were set up a set of columns across the top and a set of rows, each row containing information on a specific unit equal to or greater than 10 MW found in the UDI World Electric Power Plants Data Base (WEPP) data base published by Platts. This set up facilitated the use of pivot tables within Excel to produce output from these worksheets. The following tables briefly describes the content / calculations in each column which was the same for all units (rows) in the worksheet. There were separate worksheets for each scenario of life extension and upgrade.

Col	Worksheet 4 and 7 – Economic Assessments for Life extension & Upgrade	
A	Region	Africa or Central America
B	Country	Extracted from WEPP data base
C	Plant Name	Extracted from WEPP data base
D	Plant Capacity (MW)	Extracted from WEPP data base
E	No. of Units	Extracted from WEPP data base
F	Unit No.	Extracted from WEPP data base
G	Unit Size (MW)	Extracted from WEPP data base
H	Year of Commissioning	Extracted from WEPP data base
I	Age (Year)	Reference year (2011) – Col H
J	Plant Factor	From Worksheet (WS 2) based on country
K	Efficiency Gain (%)	From WS 3 & 6 based on age or commission year
L	Capacity Gain (%)	From WS 3 & 6 based on age or commission year
M	Availability Gain (%)	From WS 3 & 6 based on age or commission year
N	Spill Energy Gain (MWh/yr)	0.4 x Col G x Col J x Col L x 8766
O	Energy Gain (MWh/yr)	Col G x Col J x (Col K + Col M) x 8766
P	Capacity Gain (MW)	Col G x Col L
Q	Annual Energy Benefit (US$)	(Col N + Col O) x Energy Value (WS 1)

R	**Annual Capacity Benefit (US$)**	**Col P x1000 x 12 x Capacity Value (WS 1)**
S	**PV Benefits (MUS$)**	**(Col Q + Col R) x PV(Discount Rate or Col AB, Service Life (WS 1)**
T	**Capital Costs (MUS$)**	**A x Col G^B with A and B (WS 1)**
U	**IDC (MUS$)**	**(Discount Rate (WS 1) or Col AB) x Col T / 2**
V	**Lost Production (MWh)**	**Const (WS 1) x Col G x Col J x 8766 x Months out (WS 1) /12**
W	**Lost Revenue (MUS$)**	**Col G x Months out (WS 1) x Capacity Value (WS 1) + Col V x Energy Value (WS 1)**
X	**PV Costs (MUS$)**	**Col T + Col U + Col W**
Y	**NPV (MUS$)**	**Col S – Col X**
Z	**Economic**	**"Yes" for Col Y > 0 and "No" for <= 0**
AA	**Levelized Cost (US$/MWh)**	**PMT(Discount Rate (WS 1), Service Life (WS 1), Col X) / O3**
AB	**IRR (%)**	**Macro used to solve for IRR which makes Col Y equal to 0**

B.2.4 Worksheet 5 and 8 – Output Tables for Scenarios 1 and 2

These worksheet contain pivot tables that use the information from Worksheets 4 and 7 to filter and format the results to yield the output tables. All information in the economic analysis worksheet can be pivoted into a wide variety of tables. The typical output table given in the report is composed of the following columns:

- Region
- Country
- Plant Name
- Plant Capacity (MW)
- Unit Size (MW)
- Age (Years)
- PV of Benefits (MUS$)
- PV of Costs (MUS$)
- NPV (MUS$)
- Levelized Cost (US$/MWh)
- IRR (%)

B.3 Typical Economic assessment Results

Figure B4.1 show typical result of the economic model for a range of age, capacities and plant factors and Table B4.1 shows typical results for the life extension scenario and a reference year of 2025 assuming that no rehabilitations have been carried out in the intervening period. Table B4.2 shows the equivalent results for the upgrade scenario.

Figure B4.1 – Typical Economic Assessment Results

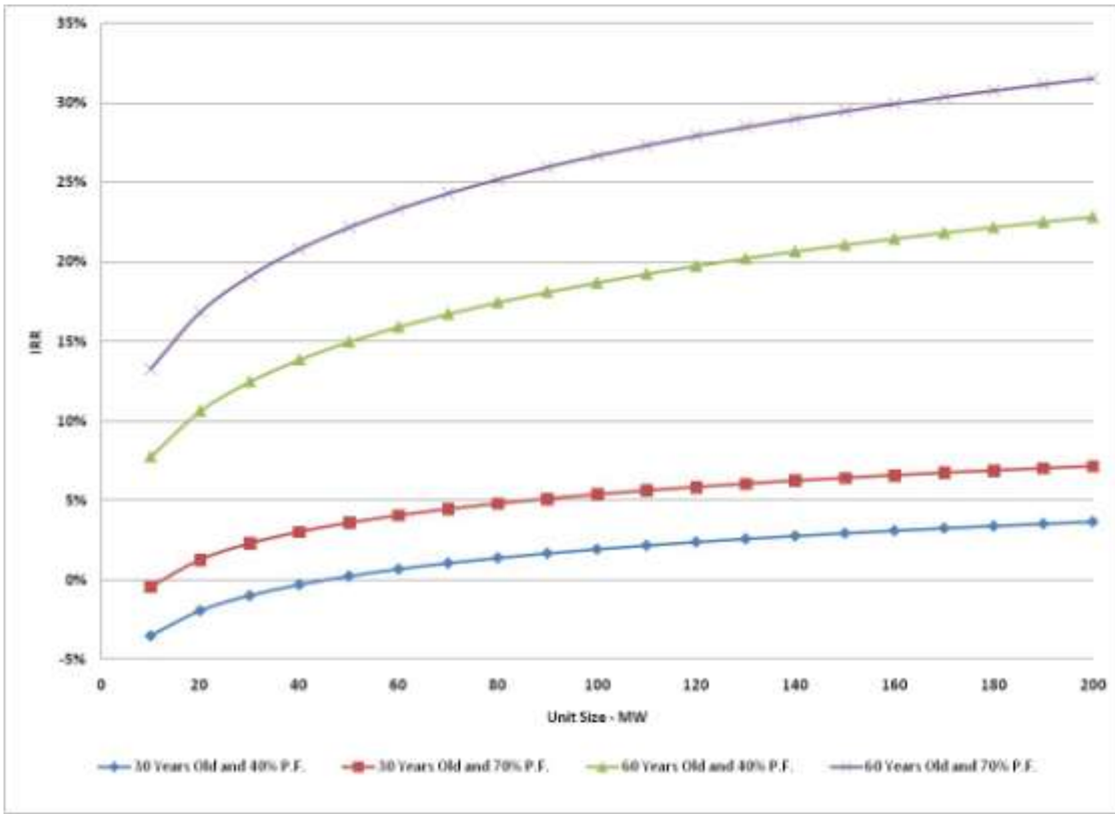

Table B4.1 – Economic Assessment Results for Life Extension in 2025

Reference Year	**2025**

Economic	**Yes**

						Values		
Region	**Country**	**Plant Name**	**Plant Capacity (MW)**	**PV of Benefits (MUS$)**	**PV of Costs (MUS$)**	**NPV (MUS$)**	**Levelized Cost (US$/MWh**	**IRR (%)**

							)	
Africa	**Angola**	**Biopio**	**14.6**	**$15**	**$6**	**$9**	**$44**	**22.0%**
		Cambambe	**180.0**	**$129**	**$61**	**$68**	**$55**	**18.5%**
		Matala	**41.4**	**$45**	**$22**	**$23**	**$53**	**18.3%**
		Rio Luachimo	**16.0**	**$18**	**$7**	**$11**	**$41**	**23.6%**
	Burkina Faso	**Kompienga**	**15.4**	**$9**	**$8**	**$1**	**$105**	**8.9%**
	Burundi	**Rwegura**	**19.2**	**$12**	**$9**	**$2**	**$91**	**10.6%**
	Cameroon	**Edea**	**264.6**	**$241**	**$123**	**$118**	**$59**	**17.3%**
		Lagdo	**80.0**	**$37**	**$37**	**$1**	**$112**	**8.2%**
		Song-Loulou	**396.0**	**$184**	**$132**	**$53**	**$83**	**12.1%**
	Congo	**Budana**	**13.5**	**$20**	**$6**	**$14**	**$32**	**29.6%**
		Inga I	**58.5**	**$42**	**$25**	**$17**	**$66**	**14.9%**
		Inga Ii	**712.0**	**$360**	**$155**	**$205**	**$49**	**20.6%**
		Koni	**42.1**	**$55**	**$22**	**$33**	**$44**	**21.9%**
		Mobayi	**11.5**	**$2**	**$2**	**$0**	**$114**	**8.1%**
		Mwadingusha	**68.0**	**$120**	**$38**	**$82**	**$35**	**27.1%**
		N'seke	**195.0**	**$217**	**$59**	**$158**	**$30**	**31.5%**
		N'zilo	**81.0**	**$97**	**$33**	**$64**	**$37**	**25.4%**
		Piana Mwanga	**29.5**	**$54**	**$15**	**$39**	**$30**	**31.1%**
		Ruzizi I	**28.2**	**$24**	**$14**	**$10**	**$65**	**15.8%**
		Zongo	**75.0**	**$76**	**$38**	**$38**	**$54**	**17.9%**
	Congo Republic	**Djoue**	**15.0**	**$16**	**$7**	**$8**	**$51**	**18.8%**
		Moukoukoulou	**74.0**	**$38**	**$35**	**$3**	**$104**	**8.9%**
	Cote D'ivoire	**Ayame-1**	**27.4**	**$28**	**$14**	**$14**	**$57**	**17.1%**
		Ayame-2	**30.4**	**$26**	**$15**	**$11**	**$65**	**15.0%**
		Buyo	**171.0**	**$89**	**$54**	**$35**	**$69**	**14.5%**
		Kossou	**174.0**	**$120**	**$55**	**$66**	**$51**	**19.5%**
		Taabo	**210.0**	**$116**	**$62**	**$54**	**$60**	**16.6%**

Egypt	**Aswan High Dam**	**2100.0**	**$1,517**	**$455**	**$1,062**	**$33**	**28.9%**
	Aswan Low Dam	**550.0**	**$373**	**$180**	**$194**	**$57**	**19.1%**
Ethiopia	**Awash I (Koka)**	**45.6**	**$41**	**$23**	**$18**	**$62**	**15.7%**
	Awash Ii	**32.0**	**$24**	**$16**	**$8**	**$73**	**13.4%**
	Awash Iii	**32.0**	**$21**	**$16**	**$5**	**$85**	**11.3%**
	Fincha	**133.9**	**$61**	**$38**	**$23**	**$70**	**14.2%**
Gabon	**Kinguele**	**57.6**	**$36**	**$28**	**$8**	**$88**	**10.9%**
	Poubara	**37.8**	**$11**	**$8**	**$3**	**$79**	**12.3%**
	Tchimbele	**68.4**	**$24**	**$20**	**$4**	**$94**	**10.2%**
Ghana	**Akosombo**	**1020.0**	**$769**	**$223**	**$546**	**$32**	**29.8%**
	Kpong	**182.8**	**$89**	**$62**	**$27**	**$79**	**12.6%**
Guinea	**Donkea**	**16.4**	**$11**	**$8**	**$3**	**$85**	**11.4%**
	Grandes Chutes	**30.2**	**$10**	**$6**	**$4**	**$63**	**15.5%**
Kenya	**Gitaru**	**228.7**	**$58**	**$41**	**$17**	**$81**	**12.2%**
	Kamburu	**90.0**	**$40**	**$35**	**$5**	**$99**	**9.7%**
	Kindaruma	**44.0**	**$24**	**$19**	**$5**	**$89**	**10.7%**
	Tana	**14.4**	**$13**	**$5**	**$8**	**$42**	**23.9%**
Madagascar	**Andekaleka**	**62.0**	**$47**	**$25**	**$22**	**$60**	**16.5%**
	Mandraka-I	**24.0**	**$33**	**$12**	**$22**	**$39**	**24.8%**
Malawi	**Nkula-A**	**24.0**	**$19**	**$12**	**$7**	**$72**	**13.4%**
	Nkula-B	**100.0**	**$30**	**$27**	**$2**	**$104**	**9.0%**
	Tedzani Falls	**91.6**	**$13**	**$12**	**$1**	**$103**	**8.9%**
Mauritius	**Ferney**	**10.0**	**$4**	**$4**	**$0**	**$110**	**8.3%**
	Tamarin Falls	**11.4**	**$6**	**$2**	**$3**	**$46**	**21.3%**
Mozambique	**Cahora Bassa**	**2075.0**	**$1,501**	**$364**	**$1,137**	**$27**	**35.4%**
	Chicamba	**38.4**	**$38**	**$18**	**$20**	**$52**	**18.6%**
	Mavuzi	**52.0**	**$71**	**$27**	**$44**	**$40**	**24.3%**
Namibia	**Ruacana**	**240.0**	**$136**	**$68**	**$68**	**$56**	**17.8%**
Nigeria	**Jebba**	**578.4**	**$25**	**$24**	**$1**	**$113**	**8.4%**

		Kainji	760.0	$281	$192	$89	$78	12.9%
	Reunion	Riviere De L'est	45.3	$32	$20	$12	$76	13.1%
		Takamaka	43.4	$17	$9	$8	$60	16.4%
	Rwanda	Mukungwa-1	12.4	$8	$6	$2	$85	11.3%
	South Africa	Drakensberg	1000.0	$89	$88	$1	$119	8.1%
		Second Falls	11.0	$12	$5	$7	$45	21.1%
	Sudan	Khasm El Girba	17.8	$14	$7	$6	$57	17.5%
		Roseires	280.0	$118	$85	$34	$85	12.0%
		Sennar	15.0	$12	$7	$5	$68	14.3%
	Swaziland	Edwaleni	15.0	$23	$6	$17	$28	32.9%
		Lupohlo	20.8	$14	$13	$1	$103	9.1%
	Tanzania	Hale Tanesco	21.0	$16	$12	$4	$82	11.7%
		Kidatu	200.0	$102	$65	$37	$73	13.7%
		Mtera	80.0	$28	$28	$0	$115	8.0%
	Uganda	Nalubaale	180.0	$148	$84	$64	$64	15.5%
	Zambia	Kafue Gorge	930.0	$637	$212	$425	$37	26.2%
		Kariba North	660.0	$444	$147	$297	$37	26.3%
		Lusemfwa	15.9	$21	$7	$14	$37	26.4%
		Lusiwasi	12.0	$8	$5	$4	$62	15.9%
		Mulungushi	16.2	$28	$7	$21	$29	31.8%
		Victoria Falls	108.0	$90	$62	$28	$68	19.7%
	Zimbabwe	Kariba South	680.0	$753	$173	$580	$25	36.7%
Africa Total				$10,131	$4,073	$6,058	$61	18.8%
C. America	Costa Rica	Arenal	157.4	$86	$51	$35	$67	14.8%
		Belen Cnfl	10.9	$5	$1	$4	$16	53.4%
		Birris	22.7	$6	$3	$3	$47	21.6%
		Cachi Ice	100.8	$74	$38	$36	$59	17.1%
		La Garita	30.0	$31	$15	$16	$53	18.2%

	Miguel Dengo Benavides	**180.0**	**$89**	**$56**	**$33**	**$71**	**14.0%**
	Rio Macho	**120.0**	**$87**	**$51**	**$36**	**$65**	**15.1%**
	Ventanas Cnfl	**10.0**	**$14**	**$4**	**$10**	**$28**	**32.9%**
	Ventanas-Garita	**97.4**	**$39**	**$32**	**$7**	**$95**	**10.2%**
El Salvador	**15 De Septiembre**	**156.6**	**$65**	**$44**	**$21**	**$77**	**12.9%**
	5 De Noviembre	**81.4**	**$75**	**$40**	**$35**	**$59**	**16.7%**
	Cerron Grande	**172.8**	**$93**	**$47**	**$46**	**$57**	**17.5%**
	Guajoyo	**15.0**	**$12**	**$9**	**$3**	**$82**	**11.7%**
Guatemala	**Aguacapa**	**90.0**	**$50**	**$36**	**$15**	**$80**	**12.2%**
	Chixoy (Pueblo Viejo)	**300.6**	**$150**	**$94**	**$56**	**$69**	**14.7%**
	Jurun Marinala	**69.0**	**$57**	**$30**	**$27**	**$59**	**16.6%**
	Los Esclavos	**14.0**	**$13**	**$7**	**$6**	**$59**	**16.6%**
Honduras	**Canaveral Enee**	**29.0**	**$22**	**$15**	**$7**	**$74**	**13.2%**
	El Cajon (F Moran)	**303.4**	**$114**	**$86**	**$27**	**$91**	**10.9%**
	Rio Lindo	**80.0**	**$41**	**$36**	**$5**	**$100**	**9.4%**
Mexico	**27 De Septiembre**	**59.4**	**$36**	**$27**	**$10**	**$82**	**11.8%**
	A Figueroa (La Venta)	**30.0**	**$17**	**$14**	**$3**	**$93**	**10.2%**
	Aguamilpa	**960.0**	**$179**	**$164**	**$15**	**$110**	**9.0%**
	Angostura (Dominguez)	**900.0**	**$345**	**$185**	**$160**	**$61**	**16.5%**
	Boquilla	**25.0**	**$40**	**$12**	**$28**	**$31**	**29.5%**
	Camilo Arriaga (El Salto)	**18.0**	**$10**	**$9**	**$0**	**$109**	**8.3%**
	Chicoasen (Torres)	**2430.0**	**$501**	**$262**	**$239**	**$60**	**17.0%**
	Chilapan	**26.0**	**$15**	**$13**	**$2**	**$89**	**11.2%**
	Colimilla	**51.2**	**$41**	**$27**	**$14**	**$72**	**13.4%**

Cupatitzio	**72.5**	**$43**	**$26**	**$17**	**$67**	**14.7%**
El Cobano	**52.0**	**$37**	**$21**	**$16**	**$63**	**15.6%**
El Duranzo	**18.0**	**$13**	**$9**	**$4**	**$80**	**11.9%**
Encanto	**10.0**	**$8**	**$4**	**$4**	**$60**	**16.2%**
Falcon	**31.5**	**$23**	**$18**	**$5**	**$87**	**11.0%**
Humaya	**90.0**	**$35**	**$30**	**$5**	**$97**	**9.9%**
Infiernillo	**960.0**	**$476**	**$206**	**$270**	**$50**	**20.4%**
Ixtapantongo	**51.8**	**$38**	**$20**	**$18**	**$58**	**17.0%**
Jc Del Valle (El Retiro)	**21.0**	**$11**	**$10**	**$1**	**$105**	**8.8%**
Juntas	**15.0**	**$16**	**$7**	**$9**	**$50**	**20.3%**
Lerma	**60.0**	**$56**	**$27**	**$29**	**$53**	**18.3%**
Malpaso (Cfe)	**1080.0**	**$488**	**$222**	**$265**	**$53**	**19.4%**
Mazatepec	**208.8**	**$123**	**$66**	**$57**	**$60**	**16.5%**
Minas (Cfe)	**15.0**	**$12**	**$6**	**$5**	**$62**	**15.8%**
Necaxa	**113.5**	**$180**	**$56**	**$124**	**$34**	**28.4%**
Oviachic	**19.2**	**$13**	**$10**	**$3**	**$86**	**11.0%**
Patla	**45.6**	**$75**	**$23**	**$53**	**$32**	**28.5%**
Penitas (Corzo)	**421.2**	**$109**	**$104**	**$5**	**$112**	**8.5%**
Plutarco Elias Calles	**135.0**	**$68**	**$45**	**$23**	**$77**	**13.2%**
Puente Grande	**17.4**	**$22**	**$8**	**$14**	**$33**	**32.5%**
Ramirez (El Caracol)	**594.7**	**$155**	**$118**	**$37**	**$89**	**11.3%**
S Alvarado (Sanalona)	**14.0**	**$8**	**$7**	**$1**	**$94**	**10.1%**
Santa Rosa (Dieguez)	**61.2**	**$35**	**$23**	**$11**	**$76**	**12.9%**
Temascal	**354.1**	**$99**	**$54**	**$45**	**$61**	**16.2%**
Tepazolco	**10.9**	**$8**	**$5**	**$3**	**$65**	**15.0%**
Tepexic	**44.8**	**$74**	**$22**	**$52**	**$32**	**28.4%**

		Tuxpango	36.0	$50	$18	$32	$37	26.1%
		Villita (Morelos)	295.0	$128	$82	$45	$73	13.6%
	Nicaragua	Centroamerica	50.0	$42	$21	$21	$55	17.7%
		Santa Barbara Nic	50.0	$34	$21	$13	$69	14.1%
	Panama	Bayano	260.0	$94	$47	$47	$56	17.7%
		Edwin Fabrega (Fortuna)	300.0	$121	$77	$43	$74	13.7%
		Gatun Dam	22.5	$51	$9	$42	$19	45.5%
		La Estrella	43.0	$21	$19	$2	$101	9.3%
		Los Valles	50.0	$24	$21	$3	$97	9.8%
		Madden Dam	36.0	$56	$20	$36	$38	24.5%
C. America Total				$5,152	$2,890	$2,262	$65	17.9%
Grand Total				$15,283	$6,963	$8,320	$63	18.5%

Table B4.2 – Economic Assessment Results for Upgrade in 2025

Reference Year	2025
Economic	Yes

				Values				
Region	Country	Plant Name	Plant Cap (MW)	PV of Benefits (MUS$)	PV of Costs (MUS$)	NPV (MUS$)	Levelized Cost (US$/ MWh)	IRR (%)
Africa	Algeria	Darguinah	66	$36	$35	$1	$155	8.3%
	Angola	Biopio	14.6	$21	$8	$12	$55	21.6%
		Cambambe	180	$176	$88	$89	$70	17.6%

	Matala	41.4	$63	$31	$32	$67	17.8%
	Rio Luachimo	16	$25	$10	$16	$51	23.0%
Burundi	Rwegura	19.17	$14	$13	$0	$116	8.1%
Cameroon	Edea	264.6	$333	$178	$155	$75	16.5%
	Song-Loulou	396	$171	$141	$30	$98	10.3%
Congo	Budana	13.5	$28	$8	$20	$40	28.7%
	Inga I	58.5	$58	$33	$25	$77	15.7%
	Inga Ii	712	$419	$215	$204	$60	17.3%
	Koni	42.12	$77	$32	$45	$55	21.1%
	Mwadingusha	68.04	$169	$56	$113	$44	26.1%
	N'seke	195	$306	$84	$222	$37	31.1%
	N'zilo	81	$137	$48	$89	$47	24.8%
	Piana Mwanga	29.5	$76	$20	$55	$34	32.1%
	Ruzizi I	28.2	$34	$20	$14	$83	15.2%
	Zongo	75	$108	$55	$53	$69	17.4%
Congo Republic	Djoue	15	$22	$11	$12	$65	18.2%
Cote D'ivoire	Ayame-1	27.4	$39	$21	$18	$72	16.6%
	Ayame-2	30.4	$37	$22	$15	$83	14.6%
	Buyo	171	$103	$77	$27	$87	11.6%
	Kossou	174	$166	$78	$88	$64	18.8%
	Taabo	210	$139	$88	$51	$76	13.9%
Egypt	Aswan High Dam	2100	$2,153	$633	$1,520	$41	29.3%
	Aswan Low Dam	550	$501	$257	$244	$72	17.9%
Ethiopia	Awash I (Koka)	45.6	$58	$33	$24	$79	15.2%
	Awash Ii	32	$34	$23	$11	$93	13.1%
	Awash Iii	32	$29	$23	$6	$109	10.9%
	Fincha	133.9	$83	$54	$29	$89	13.4%
Gabon	Kinguele	57.6	$47	$41	$6	$113	9.7%

	Poubara	**37.76**	**$15**	**$12**	**$3**	**$101**	**11.0%**
Ghana	**Akosombo**	**1020**	**$1,091**	**$310**	**$781**	**$40**	**30.2%**
	Kpong	**182.8**	**$104**	**$89**	**$15**	**$100**	**9.9%**
Guinea	**Donkea**	**16.4**	**$16**	**$12**	**$4**	**$109**	**11.1%**
	Grandes Chutes	**30.2**	**$15**	**$9**	**$6**	**$81**	**15.1%**
Kenya	**Gitaru**	**228.7**	**$72**	**$59**	**$13**	**$103**	**10.4%**
	Kamburu	**90**	**$54**	**$50**	**$4**	**$126**	**8.9%**
	Kindaruma	**44**	**$35**	**$28**	**$7**	**$115**	**10.7%**
	Tana	**14.4**	**$19**	**$8**	**$12**	**$53**	**23.7%**
Madagascar	**Andekaleka**	**62**	**$54**	**$36**	**$19**	**$76**	**13.3%**
	Mandraka-I	**24**	**$46**	**$17**	**$29**	**$50**	**24.0%**
Malawi	**Nkula-A**	**24**	**$27**	**$18**	**$9**	**$93**	**13.1%**
	Tedzani Falls	**91.6**	**$17**	**$17**	**$0**	**$134**	**8.1%**
Mauritius	**Ferney**	**10**	**$6**	**$6**	**$0**	**$142**	**8.2%**
	Tamarin Falls	**11.383**	**$8**	**$3**	**$5**	**$58**	**21.3%**
Mozambique	**Cahora Bassa**	**2075**	**$1,847**	**$488**	**$1,360**	**$32**	**32.5%**
	Chicamba	**38.4**	**$54**	**$26**	**$28**	**$67**	**18.2%**
	Mavuzi	**52**	**$99**	**$39**	**$60**	**$50**	**23.5%**
Namibia	**Ruacana**	**240**	**$158**	**$96**	**$62**	**$70**	**14.5%**
Nigeria	**Kainji**	**760**	**$388**	**$274**	**$114**	**$99**	**12.5%**
Reunion	**Riviere De L'est**	**45.3**	**$38**	**$29**	**$9**	**$96**	**10.6%**
	Takamaka	**43.4**	**$24**	**$13**	**$11**	**$76**	**15.9%**
Rwanda	**Mukungwa-1**	**12.4**	**$9**	**$9**	**$1**	**$109**	**8.7%**
South Africa	**Gariep**	**360.791**	**$69**	**$65**	**$4**	**$152**	**8.6%**
	Second Falls	**11**	**$17**	**$7**	**$10**	**$53**	**21.6%**
Sudan	**Khasm El Girba**	**17.8**	**$19**	**$11**	**$9**	**$72**	**17.3%**
	Roseires	**280**	**$117**	**$81**	**$36**	**$93**	**12.5%**
	Sennar	**15**	**$17**	**$11**	**$6**	**$87**	**14.0%**
Swaziland	**Edwaleni**	**15**	**$32**	**$9**	**$23**	**$35**	**32.2%**

	Tanzania	**Hale Tanesco**	**21**	**$23**	**$18**	**$6**	**$105**	**11.4%**
		Kidatu	**200**	**$128**	**$94**	**$34**	**$92**	**11.8%**
	Uganda	**Nalubaale**	**180**	**$212**	**$123**	**$89**	**$82**	**15.2%**
	Zambia	**Kafue Gorge**	**930**	**$858**	**$294**	**$563**	**$46**	**25.3%**
		Kariba North	**660**	**$595**	**$204**	**$391**	**$46**	**25.4%**
		Lusemfwa	**15.9**	**$30**	**$10**	**$19**	**$47**	**25.6%**
		Lusiwasi	**12**	**$11**	**$7**	**$5**	**$79**	**14.9%**
		Mulungushi	**16.2**	**$40**	**$11**	**$29**	**$36**	**30.8%**
		Victoria Falls	**108**	**$126**	**$90**	**$36**	**$87**	**19.1%**
	Zimbabwe	**Kariba South**	**680**	**$1,057**	**$242**	**$815**	**$31**	**36.6%**
Africa Total				**$13,211**	**$5,358**	**$7,853**	**$73**	**18.8%**
C. America	**Costa Rica**	**Arenal**	**157.398**	**$102**	**$73**	**$29**	**$85**	**12.1%**
		Belen Cnfl	**10.9**	**$7**	**$1**	**$6**	**$19**	**52.5%**
		Birris	**22.72**	**$9**	**$4**	**$5**	**$60**	**21.2%**
		Cachi Ice	**100.8**	**$101**	**$55**	**$46**	**$74**	**16.3%**
		La Garita	**30**	**$44**	**$22**	**$22**	**$68**	**17.6%**
		Miguel Dengo Benavides	**180**	**$104**	**$79**	**$24**	**$90**	**11.2%**
		Rio Macho	**120**	**$118**	**$73**	**$45**	**$83**	**14.3%**
		Ventanas Cnfl	**10**	**$20**	**$5**	**$14**	**$35**	**32.2%**
	El Salvador	**15 De Septiembre**	**156.6**	**$76**	**$62**	**$14**	**$97**	**10.3%**
		5 De Noviembre	**81.4**	**$106**	**$58**	**$48**	**$75**	**16.3%**
		Cerron Grande	**172.8**	**$119**	**$66**	**$52**	**$71**	**15.8%**
		Guajoyo	**15**	**$17**	**$12**	**$5**	**$99**	**12.1%**
	Guatemala	**Aguacapa**	**90**	**$59**	**$51**	**$7**	**$102**	**9.5%**
		Chixoy (Pueblo Viejo)	**300.603**	**$175**	**$133**	**$42**	**$86**	**11.9%**
		Jurun Marinala	**69**	**$80**	**$44**	**$37**	**$75**	**16.2%**

	Los Esclavos	14	$18	$10	$8	$75	16.2%
Honduras	Canaveral Enee	29	$32	$22	$10	$94	12.9%
	El Cajon (F Moran)	303.4	$132	$121	$11	$109	9.0%
Mexico	27 De Septiembre	59.4	$53	$39	$14	$105	11.7%
	A Figueroa (La Venta)	30	$24	$20	$4	$119	10.2%
	Angostura (Dominguez)	900	$447	$261	$186	$77	15.1%
	Boquilla	25	$58	$17	$41	$37	29.1%
	Camilo Arriaga (El Salto)	18	$14	$14	$0	$141	8.3%
	Chicoasen (Torres)	2430	$585	$364	$221	$74	14.1%
	Chilapan	26	$22	$18	$3	$114	11.2%
	Colimilla	51.2	$60	$40	$20	$91	13.2%
	Cupatitzio	72.45	$63	$38	$25	$85	14.7%
	El Cobano	52.02	$54	$31	$23	$80	15.5%
	El Duranzo	18	$19	$14	$5	$103	11.8%
	Encanto	10	$11	$6	$5	$76	16.0%
	Falcon	31.5	$33	$26	$7	$111	10.8%
	Humaya	90	$46	$43	$3	$124	8.8%
	Infiernillo	960	$680	$290	$390	$62	20.6%
	Ixtapantongo	51.75	$55	$27	$28	$69	20.5%
	Jc Del Valle (El Retiro)	21	$16	$15	$1	$135	8.8%
	Juntas	15	$23	$9	$13	$63	20.1%
	Lerma	60	$80	$39	$41	$66	18.0%
	Malpaso (Cfe)	1080	$687	$313	$374	$66	19.3%
	Mazatepec	208.8	$178	$95	$84	$76	16.6%
	Minas (Cfe)	15	$17	$9	$7	$78	15.6%

	Necaxa	113.5	$259	$82	$177	$41	27.9%
	Oviachic	19.2	$19	$15	$4	$110	10.9%
	Patla	45.6	$108	$33	$75	$39	28.1%
	Plutarco Elias Calles	135	$96	$65	$31	$98	12.8%
	Puente Grande	17.4	$32	$11	$21	$41	32.2%
	Ramirez (El Caracol)	594.74	$183	$166	$16	$111	9.1%
	S Alvarado (Sanalona)	14	$12	$10	$2	$120	10.1%
	Santa Rosa (Dieguez)	61.2	$50	$34	$17	$97	13.0%
	Temascal	354.08	$144	$78	$66	$77	16.2%
	Tepazolco	10.88	$12	$7	$5	$83	14.8%
	Tepexic	44.82	$107	$33	$74	$39	28.0%
	Tuxpango	36	$71	$26	$46	$45	25.7%
	Villita (Morelos)	295	$178	$118	$60	$93	13.2%
Nicaragua	Centroamerica	50	$60	$30	$30	$70	17.4%
	Santa Barbara Nic	50	$47	$30	$17	$89	13.5%
Panama	Bayano	260	$122	$67	$55	$71	16.1%
	Edwin Fabrega (Fortuna)	300	$141	$109	$32	$92	11.1%
	Gatun Dam	22.5	$72	$13	$59	$23	44.6%
	Madden Dam	36	$78	$29	$50	$47	23.7%
C. America Total			$6,333	$3,577	$2,756	$77	18.0%
Grand Total			$19,545	$8,935	$10,610	$74	18.5%

Annex C

– Summary of Assessment of Case Studies

C.1 Project 1

Main Project Drivers

- Increase reliability and safety of operation, reduce maintenance and forced outages and extend equipment life
- Improve turbine performance using modern state of the art technology and more efficient turbine runners to increase generation output
- To rehabilitate the controls, metering, protection, and data logging in the powerhouse and control room.

Scoping of Investment

- Original intention was to simply refurbish the old Francis turbine runners to their original condition in order to regain the lost efficiencies that were known to have occurred as a result of cavitation and corrosion in accordance with industry standard practice.
- Results of tests on a unit indicated that the shortfall in performance was far greater than had been anticipated which led to a re-evaluation of the scope of the rehabilitation project leading to decision to upgrade the units, rather than do simple life extension, to yield significantly increased unit performance.

Decision Making

- Individual economic assessments were also carried out for the following components along with typical reported benefit cost ratios at a discount rate of 12%:
    - Runner replacement/overhaul – B/C of 1.24 for 1% efficiency increase
    - Exciter replacement – B/C ratio of 1.2
    - Generator rewind – B/C ratio of 1.8
    - Assessment of less significant components – B/C > 1 for 90% of components
    - Incremental increase in generator capacity – B/C >1.
    - A large part of the benefits came from expected reduction in outage.

Financing

- International Financing Institutions (IFIs) financed 55% of project cost with soft loans
- Owner financed 45% of the total project cost
- Sovereign guarantees were included

Project Execution

- Separate contract packages were included for each major component.
- Contract packages included supply and installation
- Owner had his own engineer to provide Engineer Procure and Construction Management (EPCM) type services and suppliers did most of the detailed design
- There were cost overruns due to the need to renegotiate the construction contract to re-scope the project to reflect doing an upgrade instead of a life extension.

Environmental / Social

- Oil containment facilities added in event of a fire involving unit transformers
- Construction activities provided some work and training for local workers
- Benefits from project continue to provide funds for resettled population from original construction

Lessons Learned

- Turbine and generator efficiency tests to verify pre- and post- equipment performance are essential as units may be performing worse than originally anticipated
- Owners / operators of the station should be involved to the maximum extent possible in both the design and implementation of the rehabilitation, since they have the most practical knowledgeable of the behaviour of the river at the project site from year to year and season to season, and they will be left with the completed project and the need to show that the project has achieved the projected results.
- Life extension option which only recovers historical efficiency and availability degradation may be significantly less economic than the option involving upgrade to more efficient and higher capacity equipment associated with modern technology
- Effective management of equipment and parts supply from foreign sources especially tools, equipment and materials with storage issues requires special attention
- Complex financing arrangement can require considerable effort from Owner’s team
- Team work and team building very important to foster friendly and harmonious environment amongst the workers and supervisors

- Project can provide workers with excellent training through close cooperation with the contractors.

C.2 Project 2

Main Project Drivers

- Increase energy and capacity at the facility with modern turbine runner designs
- Inspect existing equipment and replace or repair all worn or damaged components in order to extend the life of the units for the next 20 to 30 years
- Expansion with installation of an additional unit

Scoping of Investment

- Efficiency tests by the Original Equipment Manufacturer (OEM) showed turbine efficiency much lower than expected. Corrosion of turbine parts needed refurbishing by welding at the runner blades and guide vanes. This together with the problems of corrosion led to a decision to upgrade the units.

Decision Making

- A consultant was retained to asses the expansion upgrade project including a financial analysis
- The general conclusions reached with regard to project viability indicated a pre-project EIRR of greater than 30%
- An independent analysis of the financial model was carried out by the Lender's Engineer.

Financing

- Initially an IFI was involved in the financing
- Commercial financing was then used for implementation with the intent to refinance with permanent financing later.

Project Execution

- The partnership of turbine manufacturer and generator manufacturer was the EPC contractor for the rehabilitation work and for installation of an additional generating unit
- A consulting engineer was the Owner's representative and provided a specialist on-site to review the work completed by the EPC Contractor as well as provided assistance on an on-request basis
- No information was available on cost overruns.

Environmental / Social

- Upgrading of the existing units and the installation of an additional unit was judged to have minimal impact on the long term water regime downstream of the plant
- Construction impacts were identified as vehicular traffic, water turbidity and potential contamination by solid waste and mitigation measures were identified during the construction phase.

Lessons Learned

- Turbine performance guarantees based on model tests are quite satisfactory; however the Owner should, if possible, retain the option of performing site tests if the installation performance is suspect
- A well defined rehabilitation specification will avoid conflicts on scope of rehabilitation work during the project execution phase.
- It is not beneficial to pass all risks associated with uncertainties on equipment condition to the contractor during the bid/proposal stage.
- Appropriate and fair risk sharing is important and optional pricing for areas where condition is unknown may be beneficial.

C.3 Project 3

Main Project Drivers

- Increase energy at the facility through the increase in plant capacity, recognizing that flow in the river often exceeded the capacity of the original facility.
- Upgrade of existing turbine and generator equipment including governors and turbine inlet valve with new generating units of similar configuration but significantly higher capacity of 20%
- Replacement of the powerhouse controls
- Installation of additional transformers to accommodate the increased power levels
- Major modification to civil works to accommodate the increased discharge capacity.

Scoping of Investment

- Decision to increase capacity was made at the time of privatisation of the generating facilities and the new plant owners committed to increased capacity as part of the plant purchase agreement.

Decision Making

- A financial analysis was performed but information on the results was not available.

Financing

- Information on project financing was not available.

Project Execution

- The turbine and generator equipment manufacturer was the EPC contractor for the generating equipment rehabilitation work
- Separate contracts were implemented for the civil works, the intake gate equipment and the guard valve rehabilitation
- A consulting engineer was appointed as Owner's Representative and provided a specialist on-site to review the work completed by the contractors as well as provided assistance on an on-request basis
- There were no major cost overruns on the project but there was a claim by the EPC contractor which was settled primarily by negotiation.

Environmental / Social

- No major environmental or social issues arose during the project and since the development was located in a fairly isolated area, the there was no significant concern about changes in flows and water levels as a result of the project.
- Legacy environmental issue for the project include sediment and waste from upstream cities accumulating in the reservoir. The owner in partnership with the community has instituted several programs that have resulted in measurable reductions in erosion, sedimentation and waste.

Lessons Learned

- Owners must ensure they have a clear understanding of the requirements on how their unit(s) must perform on the transmission grid and these must be adequately passed on to the equipment supplier and equipment contractor. Otherwise electrical interconnection requirements can impact substantial completion date, which in turn impacted bonus/penalty payments. This rehabilitation project resulted from a commitment made by a new owner who may not have been informed on all the grid code requirements or there were gaps in the procedures that only came to light after the new owner took control.

- Issues such as sediment transport and its effect on equipment should not be underestimated or treated lightly in the design stage.
- Contractors need to effectively research a project and understand how the work is to be executed and the number of personnel required to undertake the work before commencing and contract conditions should be changed such that contractors carry the financial risk of not correctly estimating their costs of meeting schedule.

C.4 Project 4

Main Project Drivers

- Increase in revenue through added capacity that could utilize excess flow that was available for a significant portion of the year. There was also some added benefit to a modern turbine runner design with increased efficiency.

Scoping of Investment

- Baseline assessment was the calculation of annual generation with the existing units. The turbine performance curves from the original turbine manufacturers were used for the calculation.
- Studies were made on expanding the facility by constructing a second powerhouse. However increasing the capacity of the existing units was generally the more cost effective alternative.

Decision Making

- A financial analysis was performed. The analysis incorporated the following critical information: capital costs, energy and capacity benefits, energy prices, discount and escalation parameters.
- As the project was internally financed, decisions were made based on the projected revenue for the project.

Financing

- The project was corporate financed.
- Risk was assessed and minimized through careful project planning and including suitable warrantees and performance guarantees in the various equipment supply contracts.

Project Execution

- Equipment design and supply was through multiple contracts with equipment manufacturers
- There was a separate contract for equipment off-site mechanical rehabilitation and installation was by the operator.
- The Owner retained the services of his own engineer, independent of the contractor
- Cost overruns were generally minimal (<10% of the total project estimate) and were due to unforeseen rehabilitation work that became evident once the project was underway
- Claims were settled through negotiations.

Environmental / Social

- Small positive fisheries benefit in that with larger discharges through the turbines, reduced spill limited dissolved gases in the tailrace
- Limited long term changes to operating regime.

Lessons Learned

- Careful planning of project and site activities is essential to minimizing problems at site and preventing or minimizing site schedule delays
- Where possible, testing of a single unit upgrade performance prior to undertaking the remainder of the unit upgrades is recommended as this can lead to changes in the designs for subsequent units to maximize benefits.

C.5 Project 5

Main Project Drivers

- Provide urgently needed least-cost capacity additions to the system power generation capacity
- This was a project expansion and was not a classic rehabilitation project
- Increase the safety of the dam and associated infrastructure.

Scoping of Investment

- Current project had condition issues which required the consideration of an extension to the existing station.
- Studies were carried out on the feasibility of the expansion of the existing generating station. studies considered several alternative configurations and sizes of the extension.

Decision Making

- Economic rate of return was calculated for the broad project including extension and transmission and distribution development
- Post-project EIRR was estimated to be 13.7%, compared to a pre-project estimate of 16.5.
- Change in the EIRR attributed to a delay in completion and the high level of system losses which was not reduced over the implementation period as planned.

Financing

- IFIs and bilateral financing met the majority of the project costs
- Owner financed local costs.

Project Execution

- Separate contracts were awarded for civil works and electromechanical equipment
- A consultant was retained to provide EPCM services
- Weather related delays led to claims and cost overruns because of damage to transportation routes which were settled through arbitration.

Environmental / Social

- Environmental and social issues were raised in response to the implementation of the project and these were assessed in broad terms of provided other benefits to mitigate impacts.

Lessons Learned

- It is more efficient to initiate and implement measures to improve institutional and financial performance in advance of major new investments
- Procurement capacity should be built prior to commencement of implementation in order to avoid delays caused by poor procurement decisions
- Timely mid-term reviews are important in infrastructure projects with long implementation periods
- Risks should not just be assessed as to sensitivities of IRR to costs going up or the development period being extended a standard period, but they should be better tailored to contingency scenarios developed specifically for the project at hand

C.6 Project 6

Main Project Drivers

- Improvement of the reliability of the electric service and increase service coverage by rehabilitation, modernization and expansion of power generation, transmission, sub-transmission and distribution systems
- Purchase equipment necessary for sedimentation control.

Scoping of Investment

- Feasibility studies were completed to assess the best strategies for the rehabilitation, modernization and expansion of the power generation by several generating stations.
- This assessment did not result in a recommendation to proceed with all options under consideration

Decision Making

- Separate economic analyses were undertaken for the modernization and rehabilitation of the hydroelectric stations and the expansion of one of the stations with an additional unit was judged to be uneconomic by the government although there was no indication of the reason for this decision.
- Pre-project EIRR for all components of the project was estimated at approximately 25% and post-project was estimated at 27%

Financing

- IFIs financed approximately 60% of project cost
- Eximbanks financed approximately 20%
- Local funds covered the remainder.

Project Execution

- Multiple contracts were implemented for the various components of the project
- The Owner hired an Engineering Consultant to provide EPCM services during the Contract period
- The portion dealing with the rehabilitation and expansion of the hydroelectric projects was 8% over budget
- Rehabilitation and/or upgrade increased annual generation by 18% and extended the life by at least 20 years.

Environmental / Social

- There were no negative social or environmental impacts expected from project activities, because most components involve modernization of existing equipment.

Lessons Learned

- Project succeeded because objectives were an integral part of a broader program of sector reforms
- Well defined objectives and components led to a successful project
- Commitment and ownership shown by the entities in charge assured the success of the project.

- Dialogue with the affected stakeholders was an important element that assured the success of the project
- IFI financing requires careful attention to following the appropriate procedures to ensure that delays or cancellation of funding do not result
- Outside pressure of NGO's can result in cancellation of what would be an otherwise viable component of the project
- IFI's should discuss the conditions for the use of funds with the borrower, and/or should not finance components where other less restrictive sources of funds are available.

C.7 Project 7

Main Project Drivers

- Expansion of a completed project in order to increase the generating capacity as part of the long-term plan for the development of hydroelectric resources.
- It was justified as a least cost project in the expansion sequence but was not really a rehabilitation project given the relatively young age.

Scoping of Investment

- It was expected that the existing units would not have been subject to any major rehabilitation prior to the commencement of the extension project

Decision Making

- An economic assessment was carried out for the project and a post-project economic rate of return was estimated as 6.6%
- This low EIRR resulted from slower than anticipated demand growth

Financing

- IFI and other sources financed virtually the entire project.

Project Execution

- A civil contractor was hired to perform the plant expansion.
- The equipment manufacturer's supplied, installed and commissioned major equipment
- Consultants were retained for engineering design, studies, supervision of works, and training
- The overall actual costs were very close to the estimate, despite considerable inflation during the implementation period and various revisions to the works
- The most significant overrun was in interest during construction due to a longer than originally planned implementation period.

Environmental / Social

- There were legacy issues from the original construction of the project
- The project expansion had no identified impacts in the available documentation

- Special preventative measures needed to be implemented to prevent the start or spread of diseases among workers and the nature of these measures were indicated in the bidding document.

Lessons Learned

- Slower than anticipated growth likely resulted in the investment many years before the project was required
- There are also other cases where Greenfield developments have not been able to recover the investment in the initial period of operation due to lower than projected demand sometimes resulting from the increase in electricity prices needed to cover the costs of the new development.
- While extension / expansion projects such as this case study can be impacted by low load growth, one of the advantages of rehabilitation projects is that they are unlikely to suffer the same effect as the increment in output is smaller and a large part of the increased output is recovery of degradation and not additional generation. Project expansions have not been dealt with in the current study.
- In cases where, a project in one country depends on a market in a neighbouring country, every effort should be made to secure the market as much as possible and the residual risk should be assessed before the project is allowed to proceed.
- The need to ensure adequate geotechnical investigation.
- Review of project cost estimates by an independent consultant helps to ensure the reasonableness of these estimates and mitigates the size of actual cost overruns or under runs
- A committee of experts for periodic examination of the dam is very desirable, and in a situation where major problems are experienced, the required attention can be immediately given.

C.8 Project 8

Main Project Drivers

- Multiple hydroelectric facilities subject to larger than expected wear and tear of the generating units

Scoping of Investment

- Scale of rehabilitation critically depended on funding availability and scope was reduced to compensate.

Decision Making

- An economic evaluation, based on incremental costs and benefits, was performed for each subcomponent and then aggregated for the two main components and the project as a whole.

- The EIRR for the hydropower plant rehabilitation pre-project was found to be 17% and post-project 13% and the reduction was traced to a lack of performance in terms of capacity and energy from the rehabilitation.
- The EIRR for the system control and communications upgrade pre-project was found to be approximately 23% and post-project approximately 18%
- The EIRR for the total project was found to be approximately 18% pre-project and approximately 14% post-project which increased to approximately 18% when environmental benefits were included.

Financing

- IFIs made available 58% of the financing
- Owner made available 34% of the financing
- Co-financiers which were other governments made available 8% of the financing
- Various percentages of these funds were actually utilized.

Project Execution

- Contracts for equipment and goods estimated to cost more than US$300,000 were procured through International Competitive Bidding (ICB) using IFI bidding documents
- Domestic manufacturers competing under ICB were eligible for a 15% preference
- Consultants were selected according to the IFI rules.

Environmental / Social

- Environmental improvements were planned through enhancement of the dam safety instrumentation
- Oil leaks were eliminated by installing new environmentally safe turbines
- Environmental risks were further reduced by improving the water management of the reservoirs as a result of the installation of modem control and monitoring systems
- Important social issues were addressed by opening new job opportunities during project implementation.

Lessons Learned

- Considerable attention should be paid to the risks related to possible delays caused by the project approval by the government agencies, as well as delays during preparation and holding of procurement tender
- Feasibility Studies should pay a lot of attention to the aspects of accurate evaluation of technical condition of equipment subject to rehabilitation or repair

- A primary task during the project implementation is to identify deviations from what was planned and to initiate activities aimed at prevention of possible deviations
- Very good technical skills, strong project ownership and commitment to results on the side of the project stakeholder are critical success factors
- The presence of an enabling environment for a large scope investment is a critical success factor for the operation
- Donor coordination in project finance promotes the use of the comparative advantages of each of the donors' contributions.
- Flexibility and adaptation to changes in the project environment can overcome adverse external impacts and achieve the project development objectives.

C.9 Project 9

Main Project Drivers

- The World Bank provided assistance in restructuring the power sector, with rehabilitation of the supply system a first priority.
- Three major power stations were targeted for rehabilitation under the project.
- The project includes rehabilitating hydropower plants and distribution and transmission systems to improve technical efficiency and the quality and reliability of supply.

Scoping of Investment

- A technical audit was carried out at the plants and it was concluded that major rehab was needed to bring all three plants to design operational levels and to extend their economic life.
- The overall objective was to enhance the ability of the country's electricity supply industry to provide electricity at the lowest cost and in an efficient and sustainable manner.

Decision Making

- An economic analysis was conducted to ascertain that rehabilitation is the least cost option by comparing the costs of the alternatives to each generation component.
- The ERRs at appraisal ranged from 20.1% to 50.1%, and at project completion from 22 % to 57 % (even though neither take account of the benefits from the up-rating of the hydro plants).

Financing

- The lead lending agency was an IFI and numerous bilateral agencies were involved in the financing.

Project Execution

- The project completion report deemed the technical preparation of the project was inadequate.
- Insufficient time was allowed for both the detailed technical scoping of the work needed for rehabilitating the hydropower plants and the time required for actual implementation of the work involved.
- Viable technical alternatives were not properly assessed at the time of project preparation.
- This resulted in cost-overruns for most project components.

Environmental / Social

- The major environmental issue identified in project preparation was the treatment of wastes and harmful substances in some of the existing hydropower plants and transmission lines. An assessment of waste was included in each of the separate rehabilitation components of the PRP and their management were to be addressed during implementation. A study developed a comprehensive program for management/disposal of PCBs, in coordination with local agencies
- During implementation all transformers using PCBs were replaced and two PCB storage facilities were built, PCBs from all the project related sites are currently being stored in these facilities.

Lessons Learned

- Prior to embarking on major rehabilitation projects, sufficient time should be allowed to address policy actions, and implement measures to improve institutional and financial performance of the utility company involved.
- Inadequate technical project preparation has led to unnecessary delays during implementation and more thorough project planning, from feasibility studies leading to project inception, specification, procurement and implementation, is of paramount importance.
- Keep rehabilitation projects as focused as possible. An overly complex “Christmas tree” design, with multiple (co-) financiers, and a very ambitious, but woefully under-budgeted, program (the GTDP) overcomplicated an already complex endeavour.
- Limit the number of contract packages for the different works to a manageable level

Annex D

- Operational Risk Assessment Framework (ORAF)

Example Operational Risk Assessment Framework (ORAF) for hydropower rehabilitation

Project Development Objective(s)

The PDO is to rehabilitate the hydroelectric power plant (units (MW). Civil structures, waterway etc)

PDO Level Results Indicators	1. An increase in annual power production (total TWh, availability/reliability 2. Improved capacity for operation and maintenance 3. Legacy issues solved

Risk Category	Risk Rating and Explanation	Risk Description	Proposed Mitigation Measures	Timing for Mitigation: Prep/Impl.
1. Project Stakeholders Risks				

		Perceived negative impacts of large hydropower projects by some national and international NGOs, as well as other stakeholder	Considerable coordination and information dissemination have taken place during project preparation to increase awareness of the proposed project. A Communication strategy is developed and used Effective contract management, unbiased monitoring and transparency, and accountability especially in the implementation of the social and economic development program. Public consultation and information dissemination will be conducted during project implementation.	X X	X X
1.1 Environment		Fisheries, ecological services	Environmental flows		
1.2 Social		Resettlement, employment		X	X
1.3 Benefit Sharing		Disagreement on benefit sharing, royalties, compensation etc	Agreements reached prior to project start Updates to reflect findings, changing demands etc	X	 X
2. Operating Environment Risks					
2.1 Politics and Governance		Accountability and transparence, implementation capacity	Government reforms to increase transparency, promote democracy and make responsible parties accountable.		

2.2 Society and Security		Unrest, political conflict	Dialogue between the Government and Groups with grievances		
2.3 Environment		Natural disasters, policies, climate change	Application of land use regulation, capacity building to understand, predict and deal with disasters,		
2.4 Civil Society Capacity		Presence of CSO's Grievance mechanisms	Promote an environment where CSO's can work Work with current grievance mechanisms or establish if not present		
2.5 Systemic Fraud and Corruption		(Lack of) work to limit corruption,	Initiatives to fight corruption		
2.6 Fiduciary Management		Budgets etc	Dialogue with relevant authorities		
2.7 Economic Management		Inflation, toll barriers etc	Dialogue with relevant authorities		
2.8 Regional		Lack of regional dialogue within the framework of River Basin Authorities.	Work with these institutions to strengthen them. Seek regional benefits within the project to ensure buy-in from others.		
3.Implementing Agency Risks					

3 Implementing Agency Risks (including FM & PR risks)	[***ML***] Weak capacity at regional and local levels [***MI***] Lack of experience in complying with the Bank's procurement and FM guidelines.	Lack of project coordination across various agencies and levels (central, regional and local) leading to miscommunication, delays and cost overruns Lack of experience and capacity related to procurement and FM guidelines can result in delays	See below	X	X
3.1 Capacity	[***ML***] Weak capacity at central, regional and local levels.	There is a risk of coordination of project activities across various agencies and levels (central, regional and local).	The project can set up a coordinating unit in the utility Capacity building for the central level will be supplied by the Bank regional hub and through TA contracted by project.	X X	X X
3.2 Governance		Lack of accountability			
3.3 Fraud & Corruption		Experience with the Bank's procurement and FM guidelines.	An independent qualified private external auditor acceptable to Bank will be engaged to audit the project's accounts.		
4. Project Risks					

4.1 Design		Lack of technical (engineering) capacity Weaknesses in feasibility studies, preparation Inadequate dam safety measures Transmission capacity is inadequate to evacuate additional power.	Capacity building TA Early engagement to minimize uncertainty at early stage Update of previous dam safety routines, measurement programs etc Work with transmission authorities to remove bottlenecks, strengthen grid capacity, build additional power lines	X X X X X	X X X X X
4.2 Social and Environmental		Land acquisition/Resettlement (Legacy issues) Compensation mechanisms Environmental	Functioning grievance redress processes, and independent monitoring of compensation, relocation and rehabilitation assistance, as well as livelihood restoration outcomes for those affected, will ensure that environmental and social impacts are adequately managed.	X	

4.3 Program and Donor	**[*L*]** Donor disagreements on fiduciary safeguards **[*L*]** Donor disagreements on objectives	If the project is embedded within a broader existing power upgrading project there could be conflict over which fiduciary systems to use. Conflicting objectives for finite resources like water can lead to one project negatively impacting on the other	Agreements between donors on what system to use. Typically Bank systems will be used. Donor coordination prior to project implementation	X X	

4.4 Delivery Quality	[***MI***] Failure to implement project on time results in power production shortfalls [***MI***] No corporate culture for guarding value of investments [***MI***] No political will to support future maintenance shut-down	The true extent of the rehabilitation will not be known until the project is well underway. There is a risk that the program will need to be expanded. Limited incitements and understanding can negatively impact the operational capacity in the future, leading to no follow-up on maintenance plans etc	The first unit will be replaced completely to ensure a timely execution. The parts from this unit will then be analyzed to ascertain the condition of the remaining units. In a tight budgetary situation, some parts might be reused in the remaining units. Technical Assistance provided over longer term. Future engagement in order to follow up that plans are being empowered through budgets and capacity.	X	X X X

A - Proposed Rating before Concept Review:

Project Team	Risk Rating: Preparation	Risk Rating: Implementation	Date	Comments
Overall Risk				

B - Review by IL Risk Team for Concept Review:

Risk Team	Risk Rating: Preparation	Risk Rating: Implementation	Date	Comments
Overall Risk				

Final PCN Rating:

PCN Decision Chair	Risk Rating: Preparation	Processing Track	Date	Comments
Overall Risk				

Risk Ratings scale:

1=L (Low impact/Low likelihood)

2=ML (Low impact/High likelihood)

3= MI (High Impact/Low likelihood)

4= H (High Impact/High Likelihood)