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OPERATION & MAINTENANCE STRATEGIES FOR HYDROPOWER

Handbook for Practitioners and Decision Makers

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ABBREVIATIONS AND ACRONYMS

AF	Availability factor
AFNOR	Association Française de Normalisation
BAU	Business as usual
CAPEX	Capital expenditures
CMMS	Computerized maintenance management system
E-flow	Environmental flow
EPC	Engineering, procurement, and construction
ESF	Environmental and social framework
ESIA	Environmental and social impact assessment
ESMP	Environmental and social management plan
FMECA	Failure mode, effects, and criticality analysis
FOR	Forced outage rate
GW	Gigawatt
GWSP	Global Water Security & Sanitation Partnership
ICOLD	International Commission on Large Dams
ICT	Information and communications technology
IEEE	Institute of Electrical and Electronics Engineers
IHA	International Hydropower Association
INEEL	Idaho National Engineering and Environmental Laboratory
IPP	Independent power producer
ISO	International Organization for Standardization
KPI	Key performance indicator
MSC	Management service contract
MTG	Low-impact micro turbine generation technology
MW	Megawatt (1 thousand kilowatts)
NPV	Net present value
O&M	Operation and maintenance
OEM	Original equipment manufacturer
OPEX	Operating expenditures
PPA	Power purchase agreement
RCA	Root cause analysis
RCM	Reliability-centered maintenance
SECO	State Secretariat for Economic Affairs, Switzerland
SOP	Standard operating procedure
TOR	Terms of reference
TWh	Terawatt-hours (1 billion kilowatt-hours)
WHC	World Hydropower Congress

Executive summary

Photo Credits: Pierre Lorillou.

Hydropower is the world's largest source of renewable energy generation; installed capacity continues to grow, reaching 1,290 GW in 2018 (IHA, 2019), and accounting for more than 60 percent of global renewable energy generation. Its importance is also increasing as its dispatchability facilitates integration of intermittent renewables into power systems, enabling decarbonization of electricity generation.

However, operation and maintenance (O&M) of hydropower facilities are not always undertaken effectively, especially in developing countries, meaning that the full benefits of hydropower are not realized. During the Hydropower O&M Workshop in Martigny, Switzerland (October 2016) and the World Hydropower Congress (WHC) in Ethiopia (May 2017), key stakeholders from developing and developed countries agreed on the need for further in-depth discussion regarding hydropower O&M, focusing on better institutional arrangements and enhanced financial and human resources.

Whereas most generation technologies have a life of 20–30 years, a well-maintained hydropower facility can operate for more than 100 years. Good O&M practices are essential to maintaining this longevity. Facilities that are continuously maintained in good condition can operate for decades without major work, whereas facilities allowed to deteriorate require constant attention and frequent major refurbishment.

This handbook seeks to raise awareness among utility managers, decision makers, and other stakeholders of the benefits of developing robust O&M strategies for all existing hydropower plants and those under development. Unlike many other forms of generation, the cost of implementing a robust O&M strategy for hydropower accounts for a relatively small percentage of the value of electricity generated. However, failure to implement adequate and sufficient O&M can result in very high costs due to increased losses of production (direct and indirect) and higher needs for rehabilitation and equipment replacement. **Hence carrying out appropriate O&M strategies and related programs has a very high return on investment.**

This handbook also seeks to provide guidance for owners[1] preparing and implementing long-term O&M strategies. In view of the individuality of each hydropower facility, it is not possible to produce an O&M manual that suits every situation. This handbook, rather, sets out the framework and processes that should be adopted to establish an appropriate O&M strategy. It also presents the basic principles of O&M for hydropower and provides some examples of the consequences of inadequate O&M policies, programs, and procedures.

When considering improving or mobilizing adequate O&M arrangements, it is important to be able to separate upstream strategic considerations about what is the optimum option for a

[1] The handbook uses the term owner to define any party that might trigger and/or supervise preparation of an O&M strategy, including asset owners, developers, and concessionaires.

given hydropower facility or fleet, from the actual preparation and implementation of O&M programs and plans (whether multi-annual, annual, or even monthly). In order to ensure effective O&M, an O&M strategy first needs to be established, from which O&M programs and plans can then unfold. As identified as a priority at the 2017 World Hydropower Congress (WHC) by representatives of the hydropower community, this handbook focuses on the issues that need to be considered in selecting and building up an O&M strategy before discussing the actions that can be taken to support its implementation.

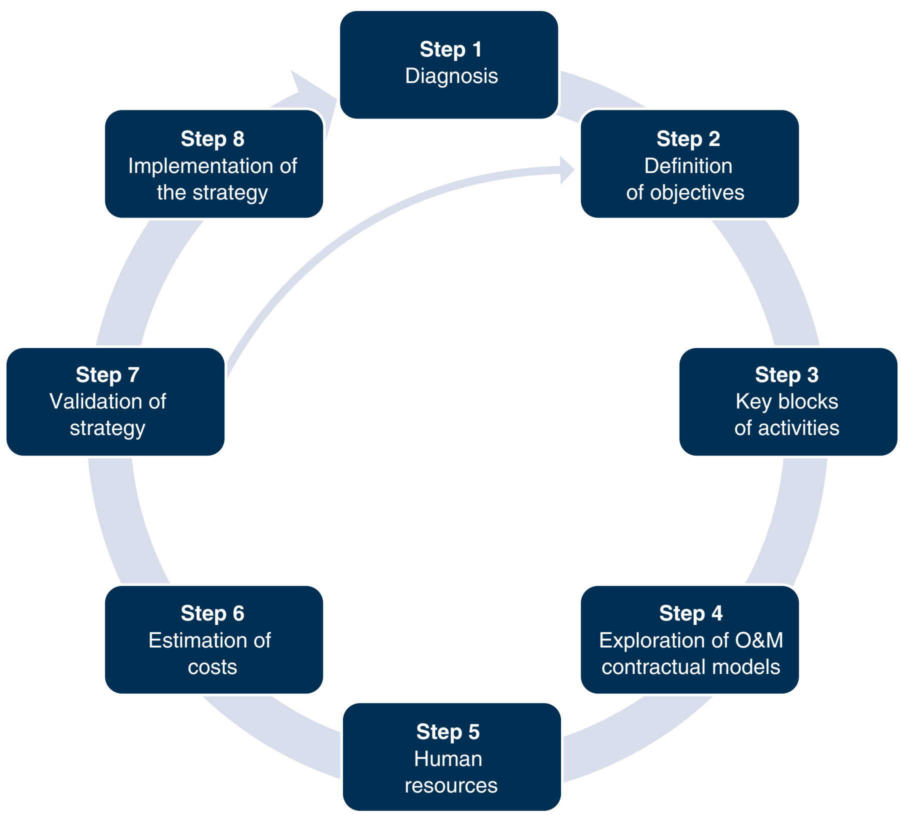
As O&M performance is a critical issue, especially in developing countries and emerging economies, the handbook focuses on strategy development and recommendations that recognize the challenges inherent in environments where further training and capacity building are needed. The handbook also recognizes the challenges that business and political environments pose for O&M performance.

The guidance in this handbook is structured though a step-by-step approach illustrated in Figure E.1.

The following steps outline the process for preparing and implementing an O&M strategy:

- **Step 1:** Carry out a diagnosis to determine the current state of the O&M program and assess the performance of the plant. A technical evaluation will also be conducted to review the condition of major equipment and infrastructure, and to assess the need for replacement and/or repairs. The diagnosis is anchored in the evaluation of key performance indicators (KPIs). In the case of a greenfield project, a diagnosis is carried out to establish the capability of the new owner to put in place a sustainable O&M strategy.
- **Step 2:** Establish the objectives to be achieved through the implementation of the O&M strategy. Objectives will target (i) meeting technical operating rules, as well as legal

FIGURE E.1 Step-by-step approach to O&M strategy development and implementation



and regulatory requirements; (ii) establishing modern maintenance management systems to preserve and prolong the life of the assets; and (iii) ensuring the safety of assets and people while protecting the environment.

- **Step 3:** Determine activities and measures to reach the strategic objectives established in Step 2 based on the diagnosis completed in Step 1. Capacity building, enhanced budgeting, improved corporate management, technical activities, etc., can be considered at this stage.
- **Step 4:** Explore O&M contractual models based on the findings from Steps 1–3. Contracts could be structured as follows:
    - Model 1: The owner retains sole responsibility for O&M.
    - Model 2: The owner outsources some O&M responsibilities to consultants, contractors, or suppliers.
    - Model 3: The owner outsources all O&M responsibility to an independent operator.

The owner's capabilities, the availability of local human resources, and the current business and political environments are all factors that should be considered when determining which model to apply. The careful distribution of responsibilities and the balanced allocation of risks should also be taken into account, particularly when formulating external service contracts.

- **Step 5:** Investigate organization and staffing options. Ensuring that the right people, with the right skills and experiences are available at the right time is essential to a successful O&M program. This step provides advice on staffing needs and timing of recruitment and training relative to construction schedules. It facilitates the development of an organization and staffing plan that identifies the internal and external resources needed, as well as the recruitment and training required.
- **Step 6:** Calculate financial resources needed for a sustainable O&M program. This step seeks to ensure that adequate funds are in place to support the implementation of the strategy, including funding for routine O&M and the provision of capital funds for major maintenance, refurbishment and modernization.
- **Step 7:** Validate the strategy through a cost-benefit analysis. If the cost-benefit analysis indicates the strategy is not viable, or if funding is not available, some of the previous steps may need to be revisited. Internal and external stakeholder consultations are also strongly encouraged at this stage for validating the O&M strategy. The handbook also provides advice on supporting actions, contracts, agreements, and special provisions required to ensure that an enabling business environment is created for the chosen O&M strategy.
- **Step 8:** Implement the O&M strategy, including by developing operating plans.

These steps are illustrated by six case studies summarized in the final chapter of this report. They cover a range of types and sizes of facilities and show the practical application of the models described in Step 4. More detailed descriptions of the case studies can be found in a companion report titled *Operation and Maintenance Strategies for Hydropower—Six Case Studies*.

The appendixes of this handbook include helpful tools for O&M development, such as an O&M lexicon (Appendix A), sample dashboards for technical diagnoses (Appendix B), typical job titles and profiles within O&M teams (Appendixes C and D), performance indicators (Appendix E), and a terms of reference (TOR) for development of an O&M strategy (Appendix F). A template operating expenditure (OPEX) budget is also provided (Appendix G).

Background and rationale for O&M strategies

Photo Credits: Arne Hoel.

Hydropower is the largest renewable energy source, accounting for 62 percent of the world's renewable energy generation, ahead of wind (21%) and solar photovoltaic (7%) (REN21, 2018). Hydropower is recognized for providing a wide range of grid-support services, such as energy storage, climate adaption, load following, and system inertia. It is also a low-cost and sustainable source of energy. The ability to dispatch hydro generation when needed and its flexibility of operation mean that it can facilitate grid integration of intermittent wind and solar generation and other non-dispatchable generation, through balancing services.

The development of hydropower continues throughout the world, with some 22 GW of hydropower being added in 2018 (IHA, 2019), bringing the world's hydropower capacity to around 1,290 GW (IHA, 2019). In 2018, the estimated generation from these facilities amounted to 4,200 TWh, or some 16 percent of the world's electricity production.

A key distinguishing feature of hydropower is its potential longevity. A hydropower facility can operate for 100 years or more, compared with 20–30 years for most other generation technologies. In fact, nearly half of the world's hydropower capacity is over 30 years old and many facilities are over 100 years old.

There are many hydropower facilities that have operated since the late 19th and early 20th centuries. Hydro Review's "Hydro Hall of Fame"[2] lists some 50 hydropower facilities in the United States and Canada that have operated continuously for over 100 years. There are many more examples worldwide. Most of these facilities have been modernized to some extent over the years, but much of the original civil works and structures remain unchanged, and turbine scrolls, draft tubes, and other heavy equipment may still be in service. This exceptional longevity is unique to hydropower.

However good O&M practices are critical to maintain this longevity. Facilities that are continuously maintained in good condition can operate for decades without major work, whereas plants that are allowed to deteriorate require constant attention and frequent major refurbishment.

For new hydropower projects, putting in place appropriate O&M strategies and programs remains a challenge, particularly in low-capacity countries where owners and operators face adverse conditions to technical and financial self-sustainability. In these plants, the full benefits of existing hydropower facilities are not being realized. This is even more evident for state-owned utilities in developing countries, where many of the new projects are located. Over 85 percent of the new hydropower capacity in 2018 was installed in Asia, Africa, or South America (IHA, 2019).

[2] https://www.hydroworld.com/index/hall-of-fame.html

Lack of effective O&M can result in loss of electricity production and revenues, high replacement fuel costs, high outage rates, performance losses, and premature large refurbishment costs. The consequent lack of reliable power can have severe economic and development costs for communities. In some countries, breakdowns in hydropower plants lead to increased use of thermal resources, with detrimental environmental consequences. Poor O&M practices can also affect employee and public safety. Serious failures can result in fatalities and environmental and property damage.

O&M is of particular importance for hydropower facilities, due to their capital-intensive nature. As a result of their bespoke design and the extensive construction works required, hydropower facilities typically take a long time to develop. When complete, they have a high value as a result of the low-cost (close to zero short-run marginal cost) energy that they can produce over their lifetime. In order to preserve this value, the facilities need to be operated and maintained well. Facilities that are allowed to degenerate will lose value and may undermine the security of the power system they serve. It can also take many years to restore a degenerated facility to good condition, and to return it to reliable and sustainable operation.

In this context, the World Bank, with the support of the Swiss State Secretariat for Economic Affairs (SECO) and in collaboration with the International Hydropower Association (IHA), is supporting the promotion of good O&M practices and models and an integrated approach for adequate services and asset-life management in hydropower.

IHA, working in conjunction with other stakeholders, has also developed general guidance for sustainable development and operation of hydropower facilities within their Hydropower Sustainability Guidelines (Hydropower Sustainability Assessment Council and IHA, 2018). These guidelines aim to define how good industry practice for hydropower should be assessed and can guide owners who are assessing their own O&M practices.

During the Hydropower Operation and Maintenance Workshop in Switzerland (October 2016) and the World Hydropower Congress (WHC) in Ethiopia (May 2017), stakeholders from developing and developed countries identified key challenges related to O&M and agreed on the need for further guidance regarding hydropower O&M, with a focus on better institutional arrangements and financial and human resources. After participatory brainstorming, stakeholders consulted at the 2017 WHC ranked the development of a handbook to support preparation of O&M strategies as a priority for the sector.

With the support of SECO through the Global Water Supply Partnership (GWSP), the World Bank agreed to facilitate the development of this handbook to assist stakeholders, especially in developing countries, in preparing an O&M strategy for existing and future hydropower assets.

A. Handbook audience and objectives

This handbook seeks to support all stakeholders engaged in O&M activities for existing facilities and new hydropower projects, particularly stakeholders in developing countries and emerging economies, where O&M performance is particularly critical, O&M capabilities are often low, and the business environment is challenging. The targeted audience includes asset owners, facility and utility managers, and decision makers from authorities, including the following:

- state-owned power utilities
- national public entities such as ministries and regulatory authorities
- regional public authorities managing cross-border assets
- private developers and independent power producers

- specialized O&M operators
- engineering, procurement, and construction contractors
- financial institutions, including development banks
- developers.

O&M service providers and consultants (who might prepare an O&M strategy) may also benefit from this handbook.

Each hydropower facility is individual in nature due to its size, location, age, configuration, purpose, environment, equipment, and a wide range of other parameters. Hence a bespoke and detailed O&M strategy is required for each hydropower facility. Although this handbook is not able to provide detailed guidance for every situation, it does set out the general processes, approach, and framework for developing an O&M strategy.

The first objective of this handbook is to raise awareness of the benefits that can be achieved through good O&M practice for (i) existing facilities or fleets, especially those with low performance and poor O&M, and (ii) for new projects under development. A strategy for O&M should be prepared as early as possible, and the handbook is expected to support stakeholders in their commitment to long-term sustainability of assets and energy services.

The second objective is to provide practical guidance for preparing an O&M strategy and engaging in downstream activities required to implement the strategy, including:

- putting in place a comprehensive set of operating procedures
- designing and implementing maintenance programs
- preparing annual operating plans
- preparing organizational and staffing plans
- identifying and preparing outsourcing support and O&M contracts
- planning adequate financial resources.

For readability, the handbook takes the perspective of asset owners concerned with how their assets will be operated and maintained and, in the case of a concession arrangement, in which state their assets will be handed back to them. As concessionaires often have similar long-term interests to those of an asset owner, they are included in the term "owner," although specific differences between public and private owners may apply, as discussed in the document.

Once owners decide to proceed with development of an O&M strategy, they will appoint internal or external experts to prepare the strategy and to implement some or all of the steps proposed in this handbook.[3]

*Note: **O&M** in this report refers to all activities needed to operate and maintain hydropower facilities, including repair and refurbishment. Even though hydropower operation and maintenance should comply with a comprehensive dam safety program, dam safety aspects are not addressed in detail in this series of reports since guidelines are already largely available on dam safety (some of them being listed in section 1.3). **Hydropower facilities** are therefore mentioned in this report as all infrastructure and equipment that deserve O&M (except dam safety) attention. It typically embodies the hydropower plant (civil works and equipment), penstocks, canals, spillways, hydro-mechanical, electrical and electronic equipment, the dam, reservoir and their vicinity (including hydro-meteorological stations).*

[3] To define and supervise the scope of work of the team, the owner may use the template terms of reference (TOR) found in Appendix G.

B. Key ingredients of O&M for hydropower

In this handbook, O&M refers to all activities needed to operate and maintain hydropower facilities, including repair and refurbishment. Modernization, including upgrades and repurposing, is generally excluded from O&M daily activities, and should be incorporated into a plant's capital works program.

O&M guidelines in this handbook seek to:

- improve efficiency and reliability of hydropower by taking into account the full life cycle of a hydropower plant, from project design, construction, commissioning, operation, and refurbishment, to end-of-life decommissioning
- protect the natural environment, employees, and surrounding communities
- maximize stakeholder benefits, including the provision of low-cost, reliable, renewable energy.

At the heart of these guidelines, and to O&M, for that matter, is good management. Measures to enhance management capability are crucial to the development and implementation of an O&M strategy. Examples of substantial improvements in performance and cost reduction through managerial reforms are explored in Case Study 1 (Statkraft) and Case Study 2 (Mount Coffee).

C. Consequences of poor O&M

Failure modes

Poor O&M can endanger employee and public safety, threaten the integrity of the facility, cause environmental damage, breach regulatory rules, and hamper financial sustainability of the utility by compromising revenues and profits. The following are examples of the kinds of failures that may occur in a hydroelectric facility:

- **Safety failures** can result in injuries and/or deaths and have environmental and social impacts. Hydropower facilities typically involve water retaining structures (dams), equipment operating under high pressure, high voltage, and large rotating machinery. The potential for safety failure is great, with a range of hazards inside and around the plant. Safety risks can result from equipment or structural failures but may also occur due to deficient design and planning, poor operation, inadequate operating guidelines, and lack of communication. Public safety risks often occur downstream of the facility, where hazardous conditions may result from uncontrolled water releases and inadequate warning systems.
- **Environmental failures** can adversely impact the environment or local communities. Hydroelectric facilities may release polluting chemicals (for example from explosions of transformers), and poor management of water, sediment releases, and inappropriate operation of reservoirs can have adverse ecological impacts. Older facilities may use potentially polluting or carcinogenic lubricants and consumables, which require containment and careful disposal. People who are displaced as a result of environmental or safety failures should be resettled and receive livelihood compensation. Such programs require management and support.
- **Regulatory failures** result from non-compliance with laws, license conditions, and regulations. A wide range of issues are covered by these regulations, including working conditions, health and safety, river management, grid codes, dispatch procedures, labor laws, and corporate governance and compliance. While direct revenue loss may not result from regulatory failure, the sanctions applied can include financial or commercial penalties, loss of licenses, and imprisonment.

- **Economic failures** can result from loss of power production, high equipment replacement, and/or reconstruction costs. These situations may result from equipment failures (such as the breakdown of stator windings, main unit transformers, or high-voltage cables), but can also result from poor practices, such as failure to clear trash screens and desilting chambers, or suboptimal operation of reservoirs. These failures can generally be predicted through monitoring, testing, and trending, which then allow timely actions to be taken to reduce economic impacts.

Examples of O&M failures

In recent years, incidents at hydropower facilities have resulted in loss of power, damaged assets, third-party property damage, and loss of life. A selection of incidents illustrated in Table 1 shows the harmful impacts of unsatisfactory O&M. Although some of the failures were a consequence of flawed design, poor O&M compounded the design defects with catastrophic consequences. Moreover, these failures could have been prevented or mitigated through effective implementation of a strong O&M strategy and adherence to procedures.

Figure 1 shows some of the damage caused by an accident at the Sayano–Shushenskaya hydroelectric facility in the Russian Federation in 2009. This accident is one of the most notorious failures due to inadequate O&M and illustrates the consequences of persistent lack of maintenance.

There are approximately 36,000 large hydroelectric dams worldwide and around 300 accidents have been reported since the International Commission on Large Dams (ICOLD, n.d.) started

TABLE 1 | Major failures at hydropower facilities, 2005–2017

HYDROPOWER FACILITY, LOCATION	DESCRIPTION	COMMISSIONING YEAR	FAILURE YEAR
Taum Sauk Hydroelectric Power Station, Missouri, United States	Faulty gauges and inadequate control systems led to overtopping of the upper reservoir and failure of a large section of the embankment, draining more than 4 million cubic meters in less than 30 minutes. There were no fatalities, but five people were injured. The failure resulted in permanent damage to the surrounding landscape. Power generation did not resume until 2010.	1962	2005
Indira Sagar, India	An estimated 300,000 people had congregated to bathe downstream from the Indira Sagar dam on the banks of the Narmada river near Dewas. Water levels rose after the dam operator opened the flood gates at night without ample warning downstream. More than 150 people were swept away. Human error and lack of dam and public safety guidelines were the main causes attributed to this accident.	2005	2005
Sayano–Shushenskaya Dam, Russia	A long chain of O&M failures culminated with excessive vibrations of one of the turbines and failure of head-cover bolts, causing destruction of the powerhouse, loss of 6 GW of power generation and 75 fatalities.	1978	2009
Dhauliganga Hydroelectric Station, India	Unprecedented flash floods in June 2013 in the State of Uttarakhand caused the complete submergence of the powerhouse. The failure resulted in massive debris accumulation, electrical equipment replacement, and loss of total generation capacity (280 MW) for more than six months.	2005	2013
Oroville Dam, United States	The spillway of the United States' tallest dam failed during operation after heavy winter rains. The emergency spillway came into operation and the slope downstream eroded rapidly. 188,000 people living downstream of the dam were evacuated.	1967	2017

FIGURE 1 | Accident at the Sayano–Shushenskaya hydroelectric facility in the Russian Federation, 2009

Source: ©REUTERS/Ilya Naymushin (2009).

keeping records in 1928.[4] ICOLD reports that the failure rate has been reduced by a factor of four over the past 40 years. Failure or inadequate capacity of the flood discharge structure is the most common cause of dam failure, which is typically a design flaw rather than a consequence of inadequate O&M. However, there is a need to periodically assess the operating parameters of existing facilities, especially with the new knowledge and understanding of the impacts of climate change.

Major failures can follow from a chain or cascade of minor events, resulting in a pathway leading to a major incident. These may be caused by improper maintenance or inadequate repairs, and failure to certify that repaired equipment is fully operational and in satisfactory condition.

In addition to catastrophic failures as illustrated above, major economic failures are relatively common. Facilities such as Inga 1 and 2 in the Democratic Republic of Congo have suffered from years of underinvestment. Case Study 3, summarized in the final chapter and presented in detail in the companion report *Operation and Maintenance Strategies for Hydropower—Case Studies,* illustrates such a failure at Kainji, where at the time of privatization in 2013, none of the eight installed units were available for generation. A facility with a theoretical value of USD 2 billion, which should have been capable of generating electricity valued in hundreds of million dollars annually, was producing nothing. After privatization, the status of the plant has improved substantially, as shown in the case study.

D. Why and when to prepare an O&M strategy

Expected benefits from an effective O&M strategy

Hydropower plants should have a very high level of availability and longer life expectancy when compared with most other generation technology, with over 95 percent availability possible under favorable conditions. Such high levels of availability will only be achieved if the facility is operated and maintained using good practices.

An effective O&M strategy will safeguard the environment and the safety of employees and the public while maximizing the benefits of the

[4] International Commission on Large Dams—ICOLD. 2017. Dams' Safety is at the very origin of the foundation of ICOLD. Available at http://www.icold-cigb.org/GB/dams/dams_safety.asp.

hydropower facilities through efficient operation and maintenance practices. It will preserve the longevity of the facility and ensure a high level of availability.

In particular, an effective hydropower O&M strategy will seek to:

- improve public, staff, and plant safety
- safeguard investment (and return on investment) throughout the life of the facility
- have a long-term (> 10 year) plan for major maintenance and rehabilitation to extend the facility's useful life
- ensure reliable and efficient operation to meet or exceed expected generation and revenue targets for the facility
- adhere to legal, regulatory, environmental, and social safeguard responsibilities and obligations
- provide effective human-resource capabilities, including training for all O&M staff and access to all required tools and information
- identify external factors that hamper the performance of O&M services and that deserve attention and communication
- raise awareness of relevance of O&M within the owner's organization and utility's staff
- support and sustain financial viability of the owners and operators.

The commercial benefits of an effective O&M strategy are clearly illustrated in the case studies summarized in the final chapter of this report and detailed in the companion report *Operation and Maintenance Strategies for Hydropower—Case Studies*. For example, in Case Study 1 covering Statkraft's assets in Brazil, greater availability (one of the parameters on which revenue is based in Brazil), over 30 percent workload (staff-hour) reductions and almost 40 percent overall cost reductions have been achieved through implementation of an improved O&M strategy.

When to prepare an O&M strategy

The main reasons for developing a new O&M strategy for a hydropower facility include the following:

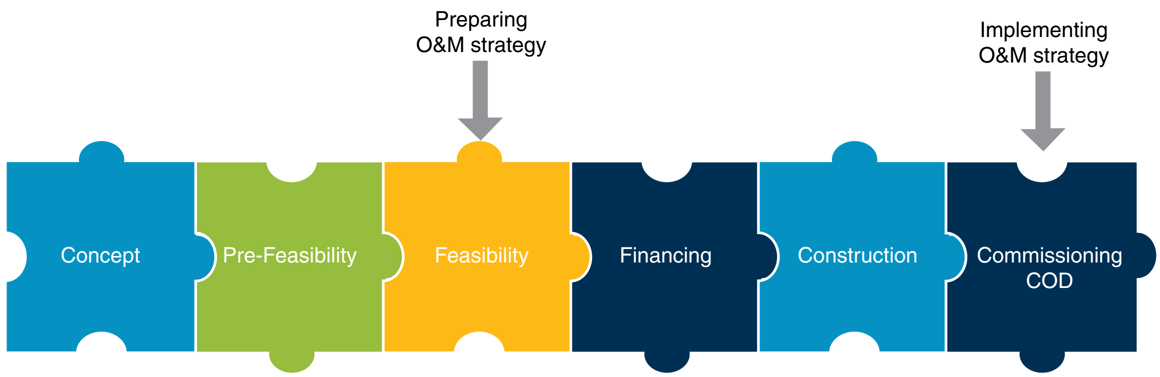
- Owners and management may recognize that the hydroelectric facility is not performing to its full potential and desire to increase revenue and profitability and reduce O&M costs.
- Owners may wish to benchmark the existing O&M practices against international best practice.
- Funders of new facilities or of refurbishment projects may require assessment of the O&M capabilities of the owners in order to ensure sustainable operation of the facilities.
- Regulators may instigate the assessment to ensure security of supply for the power grid, as well as legal/safety compliance.

Most facilities would benefit from improvements to their O&M strategy, and it should not be regarded as a failure to instigate the process outlined in this handbook. The O&M diagnosis and strategy development will also help owners and managers to improve the performance through training, application of modern tools, software and processes, and establishment of appropriate budgets.

Existing facilities: When an existing hydropower facility is not performing as expected, an O&M strategy is typically required to enable it to return to its target performance. Diagnosis of the problems based on condition assessment, production records, and other data will enable the strategy to be formulated. Some actions, such as changes to operation, can be introduced immediately at little cost, while actions requiring asset replacement, major refurbishment, and reconstruction may take years to implement.

New projects: For a new project, the approach to O&M needs to be considered at the earliest stages of development, as the strategy will

FIGURE 2 | Timing of O&M strategies for new facilities



influence project design. Collaboration between the project stakeholders, including owners, operators, designers and, where possible, equipment suppliers and contractors, will help define the concept, including the choice between a manned or unmanned facility, requirements for data acquisition and telemetry, provision of accommodation, control rooms, and other personnel-related facilities. It will also influence the design of major components such as the type of dam, choice of spillway, approach to sediment and trash management, and the extent of maintenance facilities to be provided on site. The concept should be developed to take into account the environmental and socioeconomic constraints that emerge from such stakeholder discussions.

A well-developed O&M strategy is also likely to give confidence to funders, off-takers, and authorities, by demonstrating that contractual, human resource, and organizational requirements for effective O&M were considered early in the project's design. Such a strategy will also ensure that the costs for preparation and implementation of the O&M functions are accounted for in the project's costs and the business model. In the case where the O&M capability of the owner/developer is poor, the formulation of an O&M strategy, possibly including appointment of external contractors, may be a precondition for funding. In this case early market soundings are advisable to determine the appetite of O&M contractors or advisors to participate.

For a new facility, an O&M strategy should be prepared at the feasibility stage as illustrated in Figure 2.

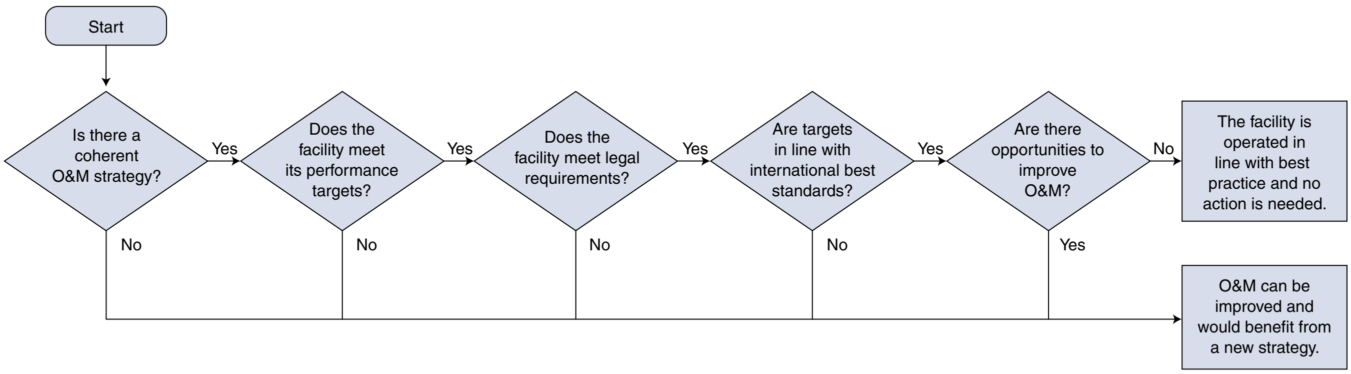
When undertaking feasibility and detailed design studies, it is now standard practice to prepare risk management matrices in order to identify, mitigate, and manage project risks at all phases, from development, construction, and operation, to decommissioning. Such a matrix should include all aspects of operation and maintenance, including technical, safety, commercial, environmental, and reputation risks. The matrix should be a dynamic document, updated regularly.

The issue of not considering the full requirements for O&M early enough are discussed in the case study for Mount Coffee (Case Study 2). Some of the capital costs of key components, such as the operators' village, workshop, and heavy maintenance equipment, were not covered by the funding for reconstruction of the project. It has subsequently proved difficult to finance these components from the revenues of the facility, leading to difficulties with staff retention and operations.

In order to help owners determine whether it is appropriate to develop a new O&M strategy for a hydropower facility or fleet of several hydropower facilities, the flowchart in Figure 3 may be used.

Whether for existing plants or for a new hydropower fleet, all O&M strategies should be

FIGURE 3 | Flowchart to establish whether a new O&M strategy is required



reviewed periodically, taking into account historic achievements, changing conditions, and potential new challenges.

E. Proposed step-by-step methodology

There is no O&M strategy that would apply to all hydropower facilities. An O&M strategy must be adapted to take into account a variety of often unique, influencing factors, including:

- country (or countries) and the scale of economic development
- location (national or multinational) and access/remoteness
- type, age, size, and capacity of the facility
- operating constraints for the facility or fleet (grid codes, Power Purchase Agreement (PPA) requirements, Environmental impact assessment (EIA) environmental license, e-flows, flood protection, gradient controls ...)
- environmental regulations imposed by the energy authority in the region
- transboundary and multipurpose issues; e.g., basin management, irrigation demands, etc.
- local transmission constraints affecting hydropower operations
- number of machine-units in the facility
- owner of the facility and its approach to O&M and safety
- capabilities of the owner(s)
- single facility or addition to an existing fleet
- role of each plant within the energy mix (of the owner and of country) and requirements for ancillary services
- technical and managerial capacity of the local workforce
- power sector maturity and facility's autonomy
- political stability and transparency in governance of O&M expenditures
- degree of regulatory independence and level of political interference.

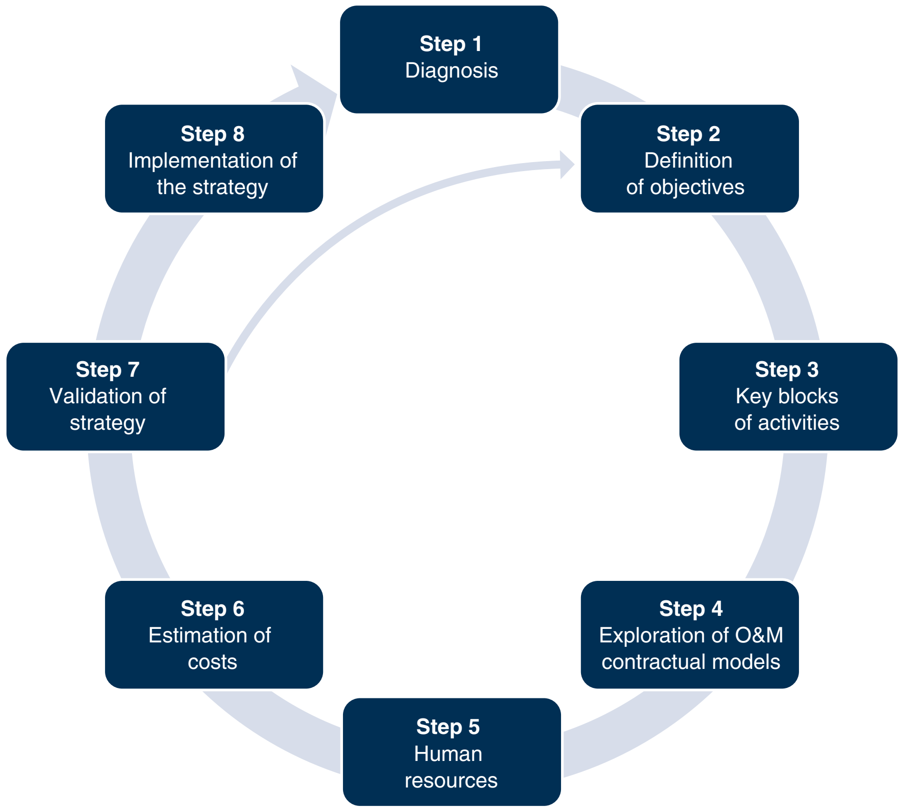
These factors need to be analyzed in order to provide insight into the design of a suitable O&M strategy, and later into more detailed O&M plans.

A step-by-step approach

This handbook provides step-by-step guidance to help decision makers and practitioners navigate the complexity of developing an O&M strategy. It includes the following eight steps and actions (Figure 4):

- **Step 1:** Diagnose existing O&M arrangements, budgets, and owner/operator capabilities. For existing hydropower fleets, assess the condition and performance of the assets and services, including risks related to major equipment and need for replacement and repairs.

FIGURE 4 | O&M strategy process



- **Step 2:** Based on this diagnosis, define the objectives to be achieved through the implementation of the O&M strategy.
- **Step 3:** Explore various activities to be undertaken to achieve these objectives.
- **Step 4:** Depending on the capabilities identified in Step 1, and activities selected in Step 3, explore O&M contractual models to identify which activities will be implemented internally and which will be outsourced.
- **Step 5:** Explore organization and staffing options (and organograms) according to owner capacity and requirements for external training and human resources.
- **Step 6:** Estimate financial resources required for implementing the selected model, including any external contracting.
- **Step 7:** Carry out cost-benefit analysis to assess the economic viability of the proposed strategy. If the strategy does not pass the test for economic viability, it may be necessary to go back to Step 2 to adjust objectives, activities, and resources. Once financial viability of the proposed strategy is achieved, internal and external validation can be sought.
- **Step 8:** Implement the strategy and prepare annual and rolling five-year operating plans and longer-term capital programs. Overall performance of the strategy will be monitored through key performance indicators (KPIs).

The final O&M strategy will include the key findings from each of the eight steps, namely a(n):

1. comprehensive **diagnosis** of the fleet, its environment, O&M practices, and resources, including issues with dam safety and socio-environmental aspects
2. clear definition of **objectives** based on KPIs
3. concrete **set of activities** that will ensure delivery of expected performance

4. selection of **contractual arrangements** with adequate mobilization of outsourced operators
5. **human resources plan,** including training, recruitments, and reorganization where needed
6. **cost estimate** of the financial resources needed to deploy the strategy
7. **cost-benefit analysis,** including a **funding plan** and **risk management plan**
8. **implementation plan,** including monitoring and evaluation arrangements.

Preparing the O&M strategy

Most organizations embarking on development of a new O&M strategy will procure an external consultant to undertake a study to prepare the strategy. A template terms of reference (TOR) for these services is provided in Appendix F and can be adapted to the needs of the owner or authority that will trigger such exercise. If the organization has the capabilities to undertake this study in-house, the TOR can provide guidelines for this internal study.

Step 1: An informed O&M diagnosis as a prerequisite to the strategy

Photo Credits: (Top left): Babar Khan.
(Bottom right): Pierre Lorillou.

The objective of Step 1 is to assess (i) the capability of the O&M teams and service providers and (ii) the performance and status of the hydropower facilities (through condition assessment). The diagnosis, including root cause analysis, identifies issues that will require particular attention in the O&M strategy. For new greenfield facilities, diagnosis focuses on determining the capability of the owners/operators through assessment of existing plants for which they have or have had responsibility.

1.1 Diagnosing O&M performance and key performance indicators (KPIs)

For a hydropower owner or operator seeking to improve safety and O&M performance of an existing fleet, it is recommended to start the preparation of an O&M strategy with a comprehensive diagnosis of existing performance. This assessment aims to determine whether safety metrics and measured performance are meeting internal and external targets, as well as the standards of good industry practice.

The intended outcome of the diagnosis is to identify what aspects of O&M need to be improved, and to establish whether the owner needs external assistance for operation of its assets. Carrying out the diagnosis is also a good preliminary tool for assessing the status of the existing equipment, prioritizing rehabilitation and, if needed, launching related feasibility studies to improve performance and ensure future safe operation.

Diagnosis of an existing fleet's performance can focus on contractual or standard industry KPIs. When financing a new facility to be added to an existing fleet, consideration should be given to the current fleet's O&M performance record. This will help guide the O&M strategy for the new facility, and possibly trigger changes to the O&M strategy for the existing fleet. Where the new project is a stand-alone facility, including those developed by an independent power producers (IPP), the same KPIs can be assessed on past or existing facilities for which the IPP team has or had responsibility.

Many different performance measures are used by electricity utilities to monitor performance of their facilities.

Table 1.1 provides commonly used KPIs for each area of performance.

In existing facilities, ideally three to five years of performance indicators will be available to establish trends, although twelve months of indicators is enough to provide a snapshot of performance. In many facilities, however, particularly poor-performing ones, this level of data may not be available. Lack of data is itself a performance indicator. In these cases, improved data collection should be an important part of the new O&M strategy.

The diagnosis step of strategy development does not need to be exhaustive. Rather, it can be a relatively high-level review that focuses on a list of the most relevant KPIs.

TABLE 1.1 Key O&M performance indicators, by performance area

TYPE OF PERFORMANCE	KEY PERFORMANCE INDICATORS
Health and safety	■ Number of lost-time injuries: accident frequency rate—number of accidents at worksite resulting in worker not being able to work in the following day(s) ■ Number of person days lost due to injuries (accident severity rate) ■ Number of high-risk incidents ■ Number of fires, explosions, or safety issues recorded per month ■ Number of car accidents within the access roads and premises of the project ■ Number of near-misses reported (number of near accidents) ■ Other indicators: ❑ Percentage of worksite visits performed by crew supervisors ❑ Staff participation in safety meetings/safety training program ❑ Implementation of accident investigation recommendations
Financial	■ Expenditures for O&M activities versus O&M budget (expressed as a percentage) ■ Cost of capital expenditures versus capital budget (expressed as a percentage) ■ Cost of special maintenance versus special maintenance budget (expressed as a percentage)
Plant (unit)	■ Plant availability factor ■ Planned outages versus actual maintenance outages ■ Unit-forced outage rate ■ Amount of water spilled (cubic meters or percent of average plant inflow) ■ Generation achieved versus theoretical output (using actual hydrology) ■ Other indicators: ❑ Emergency O&M work/total O&M work (expressed as a percentage) ❑ Maintenance work completed/maintenance work planned (expressed as a percentage) ❑ Percentage of outages investigated (root cause analysis performed) ❑ Percentage implementation of outage investigation recommendations ❑ Inventory stock levels (matching planned levels or supplier's recommendations)
Environmental impact	■ Number of incidents of noncompliance with environmental flow obligations per week ■ Number of releases of environmentally damaging products (oil, sf6, etc.) ■ Number of violations of dam safety regulations ■ Number of domestic water and sewage treatment noncompliance occurrences ■ Number of incidents involving fish mortality and strandings ■ Other indicators: ❑ Percentage of staff trained in emergency response ❑ Percentage of staff trained in dam safety ❑ Percentage of staff that have reviewed the spill response manual (annually) ❑ Number of emergency calls due to high flows and risks of overtopping
Social impact	■ Number of claims submitted by local communities and NGOs ■ Number of visits arranged for local stakeholders to the facility ■ Number of benefit-sharing actions for local communities ■ Number of activities in which power plant staff have participated to promote communication with the local community
Employee skills and relations	■ Percentage of staff who have a personal development plan ■ Percentage of performance reviews completed ■ Percentage of staff who have met the development plan objectives ■ Employee survey staff satisfaction index ■ Staff retention data (average number of years) ■ Days lost due to strikes or industrial action

TABLE 1.2 | Minimum KPIs of fleet O&M performance

KEY PERFORMANCE INDICATOR	DESCRIPTION	METHOD OF CALCULATION
Availability factor (AF)	Indicates how well the utility has managed the maintenance program to keep the generating units (station) and/or associated transmission line (if applicable) available for operation.	AF (expressed as a percentage) = (available hours/reporting period hours) × 100 Available hours are the sum of service hours (hours where the unit/line is connected to the grid) and reserve shutdown hours (unit is available but shut down for economic, hydrological, or dispatch reasons).
Forced outage rate (FOR)	Indicates the frequency of unplanned outages and correlates closely with the health of the equipment.	FOR (expressed as a percentage) = forced outage hours/(forced outage hours + service hours) × 100 FOR is the sum of all hours a unit (or line) was out of service because of immediate, delayed, or postponed forced outages. A forced outage is an outage caused by an unplanned component failure or other condition within the station that requires that a unit or line be removed from service immediately or before the next regular standstill. Service hours are the sum of all hours during which the unit is connected to the grid.
Environmental-social impact performance	Number of noncompliance incidents with environmental regulations, environmental license, and/or corporate environmental and social policies, including pollution prevention and abatement,[5] catchment management, reservoir management, downstream and compensation flow management, water quality, and social action plans.	
Accident frequency rate	Indicates the frequency of lost-time injuries in a specified period.	(Number of injuries × 100,000)/exposure hours (hours worked) A lost-time injury is an injury resulting in a worker not being able to work for some day(s) following the injury as a direct result of an occupational activity (including a journey to and from the workplace). A fatality is not considered a lost-time injury.
Accident severity rate	Indicates the seriousness of workplace injuries and/or number of injury-related fatalities	(Number of lost days × 100,000)/ exposure hours (hours worked) The number of lost days represents calendar days the employee is unable to work beyond the day of the injury. A lost-time injury is an injury resulting in lost days beyond the date of injury as a direct result of an occupational Injury.

Table 1.2 shows KPIs that provide a sufficiently high-level picture of fleet O&M performance (but not the underlying drivers).

Long-term trends should be identified in the diagnosis whenever possible to determine whether the KPIs are improving or deteriorating. Assuming that sufficient information is available to carry out a high-level review of the KPIs identified above, additional information can be sought with respect to human resource management, such as ratios of staff to energy production, installed capacity, and investment in training.

Financial metrics may be useful in understanding the adequacy of funding for plant operations and capital budgets and whether tariffs are returning enough funds to support sustainable O&M.

5 https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/policies-standards/ehs-guidelines

1.2 Systemic risk assessment

If a risk assessment does not already exist, it is strongly recommended that one is prepared. In preparing a risk-assessment matrix, each of the functional system components is assessed for the likelihood of failure and the impact/consequences of this failure on safety and revenues. Based on the combination of the likelihood and impact, the risk's criticality level is classified.

Risk analysis could be undertaken in more depth using failure mode, effects, and criticality analysis (FMECA), where failure modes are identified, the consequences defined, probabilities assigned, and criticality quantified. This process is undertaken before failures occur as a planning tool, as opposed to root cause analysis (RCA) discussed in section 1.4, which is undertaken after a failure has occurred. If FMECA has not already been undertaken for the facility, it is unlikely to be undertaken solely for the purpose of defining the O&M strategy due to cost considerations.

The number of categories for likelihood, impact, and risk level varies according to the practice of individual organizations, but it is common to use four or five categories for each. The example illustrated in Figure 1.1 uses five categories for likelihood and impact, and four categories for levels of risk.

The number of categories and their nomenclature should be established to match the terminology used by the organization in other types of risk analysis.

The five likelihood categories in this example are:

1. unlikely
2. seldom
3. occasional
4. likely
5. definite

The five impact categories in this example are:

1. insignificant
2. marginal
3. moderate
4. critical
5. catastrophic

The four levels of risk's criticality used in the example are:

1. low
2. medium
3. high
4. extreme

In order to provide consistency in the assessment, probabilities of occurrence may be associated with the likelihood categories, and financial and/or other measures (such as potential for deaths or duration of outage) can be assigned to the impact categories.

In carrying out the analysis, numerical values are assigned to each category of likelihood and impact. These are factored to derive a "risk score." A range is assigned to each level of risk, and the risk level for each component is then defined according to the range in which the risk score lies. The numeric values for the categories and the ranges may be varied to ensure that appropriate risk levels are assigned for the combination of likelihood and impact.

This can be seen in Figure 1.1. In this example, any risk with insignificant impact is classed as low, and any catastrophic risk is classed as extreme unless it is unlikely, in which case it is classified as high. There are 25 combinations of likelihood and impact.

An illustration of a high-level risk analysis for the condition of hydropower components using these categories is shown in Figure 1.2. This

FIGURE 1.1 | Matrix of risks

		IMPACT				
		INSIGNIFICANT	MARGINAL	MODERATE	CRITICAL	CATASTROPHIC
LIKELIHOOD	UNLIKELY	Low	Low	Low	Medium	High
	SELDOM	Low	Low	Medium	High	Extreme
	OCCASIONAL	Low	Medium	High	High	Extreme
	LIKELY	Low	High	HIgh	Extreme	Extreme
	DEFINITE	Low	High	High	Extreme	Extreme

high-level analysis does not consider individual risks to each component (i.e., different types of failures). Instead, it groups all units together. Typically, each unit in a multi-unit facility would be assessed separately, as they may have different ages, operation and refurbishment history, and other distinguishing features.

More sophisticated analysis can define individual risks (often several potential failure modes for an individual component), assign probabilities and revenue loss impacts, and consider mitigating measures such as insurance cover. Such analysis enables the risks to be ranked in quantitative terms. When combined using Monte-Carlo type analysis, a revenue loss-probability profile can be produced. However, such detailed analysis is not generally conducted as part of an O&M strategy development. High-level assessments are sufficient.

1.3 Condition assessment of assets

Condition assessment of most critical components of the fleet is essential for understanding the nature and scope of any works required to restore, secure, and/or modernize the facility. The need for refurbishment does not by itself indicate that there are O&M shortcomings, but the need for refurbishment could be one of the key indicators if the components are not life-expired; investigation is required to determine whether refurbishment needs are reasonable given the age and operating hours of the facilities or whether refurbishment is needed because of inadequate O&M practices. In the case of major hydro-mechanical or civil structures, the need for rehabilitation may also arise due to site conditions, a fault in the original design, or inadequate quality or construction methods.

These findings help formulate the O&M strategy and are important to determine the owner's capability to bring about changes in the operating business environment. Carrying out a condition assessment of the facility will add value in determining current and future investment requirements, particularly where plant performance indicators may not be available.

FIGURE 1.2 | Example of a risk matrix for condition of hydropower components

ID	DISCIPLINE	EQUIPMENT	HAZARD	RISK CLASSIFICATION		
				LIKELIHOOD	IMPACT	RISK LEVEL
	ELECTRICAL					
E1	Station service	Powerhouse AC station service	Plant operation failure	Occasional	Moderate	High
E2	Station service	Station lighting	Plant and staff safety	Occasional	Marginal	Medium
E3	Station service	Powerhouse DC system	Unplanned outage	Seldom	Moderate	Medium
E4	Station service	Powerhouse diesel generator	No blackstart capability	Seldom	Marginal	Low
E5	Station service	Powerhouse battery system	Plant operation failure	Occasional	Moderate	High
E6	Station service	Powerhouse station service transformer	Plant operation failure	Seldom	Moderate	Medium
E7	Station service	Fire detection system	Plant and staff safety	Seldom	Critical	High
E8	Protection and controls	Protection and control systems	Unplanned outage	Occasional	Moderate	High
E9	Governor	Unit 1 governor controls	Unplanned unit outage	Occasional	Moderate	High
E10	Substation	115 kV CBs (circuit switcher)	Unplanned outage	Seldom	Moderate	Medium
E11	Substation	115 kV surge arresters	Unplanned outage	Seldom	Moderate	Medium
E12	Substation	115 kV VTs and CTs	Unplanned outage	Seldom	Moderate	Medium
E13	Substation	GSU transformer	Unplanned outage	Seldom	Moderate	Medium
E14	Substation	DGA monitor on GSU	Unplanned outage	Seldom	Moderate	Medium
E15	MV system	4.16 kV switchgear	Unplanned outage	Seldom	Moderate	Medium
	MECHANICAL					
M1	Sluice gates	LLO gate, hydraulic actuator and HPU	Public safety failure	Unlikely	Catastrophic	High
M2	Intakes	Intake gate, hydraulic actuator and HPU	Unplanned outage	Seldom	Moderate	Medium
M3	Intakes	Trashracks and cleaner	Increased maintenance costs	Likely	Marginal	High
M4	Draft tube gates	Draft tube stoplogs and follower	Cannot perform maintenance	Seldom	Marginal	Low
M5	Ancillaries	Cooling water systems	Increased maintenance costs	Occasional	Marginal	Medium
M6	Ancillaries	Unit HPU	Increased maintenance costs	Unlikely	Marginal	Low
M7	Generators	Generator stator	Increased maintenance costs	Unlikely	Moderate	Low
M8	Generators	Generator rotor poles and exciter	Increased maintenance costs	Seldom	Moderate	Medium
M9	Turbines	Turbines unit (including runner)	Unplanned unit outage	Seldom	Moderate	Medium
M10	Water systems	Powerhouse service water system	Plant and staff safety	Occasional	Marginal	Medium
M11	HVAC	Powerhouse HVAC system	Unplanned outage	Seldom	Moderate	Medium
M12	Water systems	Sump pumps and oil water separator	Environmental hazard	Likely	Marginal	High
M13	Crane	Powerhouse OH crane (elect and controls)	Cannot perform maintenance	Occasional	Moderate	High
	CIVIL					
C1	Access road	Access road formation	Public and staff safety	Definite	Moderate	High
C2	Safety boom	Safety boom structure and floats	Plant safety	Likely	Moderate	High
C3	Debris boom	Debris boom structure and floats	Plant safety	Likely	Moderate	High
C4	Water conveyance	Diversion, intake and tailrace channel	Increased maintenance cost	Definite	Marginal	High
C5	Bridge	Bridge structure	Public and staff safety	Seldom	Moderate	Medium
C6	Main dam	Rockfill dam structure	Plant safety	Unlikely	Catastrophic	High
C7	Main dam	Instrumentation	Plant safety	Seldom	Moderate	Medium
C8	Overflow spillway	Overflow spillway concrete structure	Plant safety	Seldom	Critical	High
C9	Overflow spillway	Overflow spillway channel	Plant safety	Occasional	Critical	High
C10	Low level spillway	Low level spillway concrete structure	Plant safety	Seldom	Critical	High
C11	Low level spillway	Low level spillway waterways	Plant safety	Seldom	Critical	High
C12	Low level spillway	Low level spillway equipment building	Increased maintenance costs	Occasional	Insignificant	Low
C13	Intake	Intake pier	Increased maintenance costs	Seldom	Marginal	Low
C14	Intake	Intake deck	Staff safety	Occasional	Marginal	Medium
C15	Intake	Intake superstructure	Increased maintenance costs	Likely	Marginal	High
C16	Penstock	Penstock pipework	Plant safety	Seldom	Critical	High
C17	Penstock	Penstock ancillary structures	Plant safety	Occasional	Moderate	High
C18	Powerhouse	Powerhouse substructure	Increased maintenance costs	Unlikely	Moderate	Low
C19	Powerhouse	Powerhouse superstructure	Increased maintenance costs	Seldom	Marginal	Low
C20	Powerhouse	Powerhouse roof	Increased maintenance costs	Likely	Marginal	High
C21	Powerhouse	Turbine discharge chamber	Plant cleanliness—hygiene	Definite	Marginal	High
C22	Powerhouse	Domestic water and septic system	Staff safety	Likely	Marginal	High
C23	Powerhouse	Tailrace piers	Public safety	Seldom	Moderate	Medium
C24	Powerhouse	Tailrace deck	Staff safety	Occasional	Marginal	Medium
C25	Fish habitat	Fish habitat structures	Environmental compliance	Likely	Marginal	High
C26	General	Dam safety	Public safety	Likely	Catastrophic	Extreme
C27	General	Public safety/security	Public safety	Seldom	Critical	High

A condition assessment should provide sufficient information to inform stakeholders of the following:

- the physical condition of all assets, including electrical, mechanical, hydro-mechanical, and civil structures; associated transmission lines; switching stations; staff housing complexes; administrative buildings; and related infrastructure such as access roads, water, and wastewater management plants
- the availability of appropriate consumables, capital spare parts, and other critical replacement parts
- the availability of proper equipment, tools, and vehicles.

The diagnosis will identify unit availability, planned and forced outages, and the resulting impact on electricity production and revenue if business as usual (BAU) O&M practices continue. This BAU time series will indicate the need for improvement and to benchmark potential benefits that a new O&M strategy could bring.

Dams often present a particular safety hazard, and hence there are special requirements for their inspection and assessment, focused on safety, rather than on commercial considerations. These are often covered by national legislation, and international guidelines and guidance are available, including from the following ICOLD bulletins:

178–2017	Operation of Hydraulic Structures of Dams—Preprint
175–2018	Dam Safety Management: Pre-operational Phases of the Dam Life Cycle—Preprint
170–2018	Flood evaluation and dam safety
168–2017	Recommendations for operation, maintenance, and rehabilitation
167–2016	Regulation of dam safety: An overview of current practice world wide—Preprint
158–2018	Dam surveillance guide
154–2017	Dam safety management: Operational phase of the dam life cycle
138–2009	Surveillance: Basic elements in a “dam safety” process
130–2005	Risk Assessment in Dam Safety Management. A reconnaissance of Benefits. Methods and Current
180–2019	Dam Surveillance—Lesson learnt from case histories—Preprint

Other useful references include:

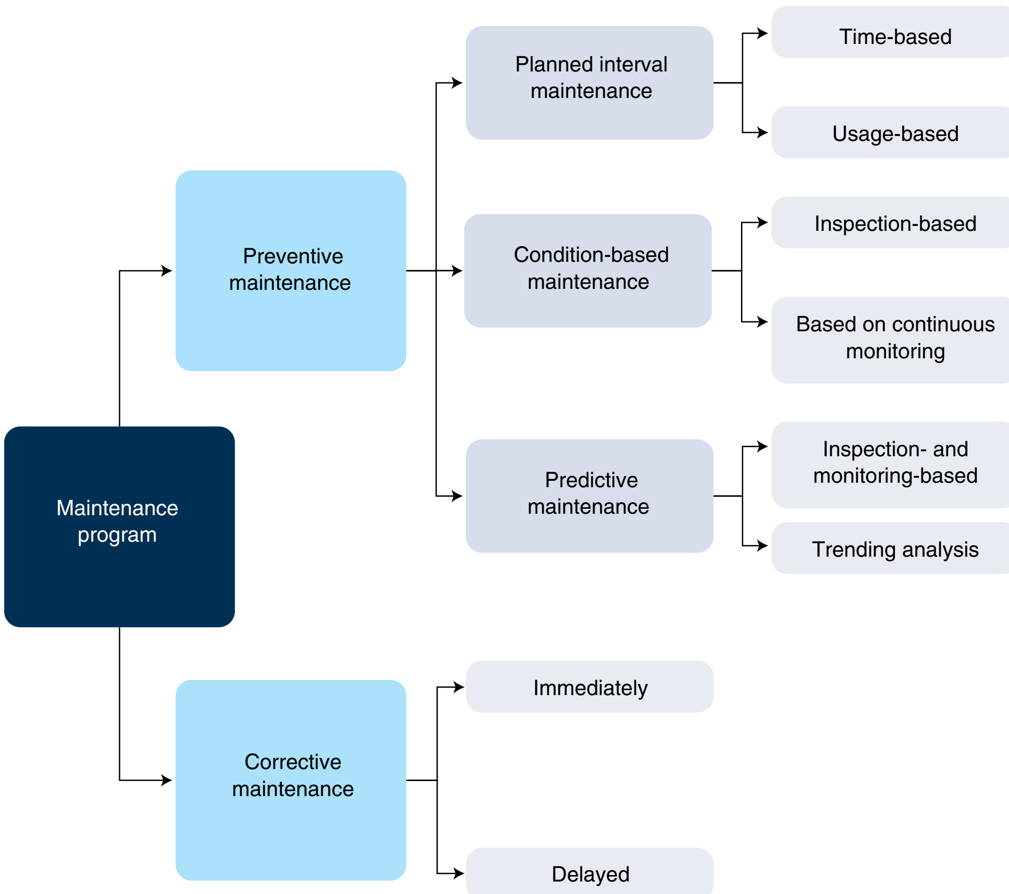
- Best Practices and Risk Methodology (USBR, 2018)
- Dam Safety Guidelines (Canadian Dam Association, 2013)
- Dam Safety Reviews Technical Bulletin (Canadian Dam Association, 2016)
- Guidelines for Instrumentation of Large Dams (Dam Rehabilitation and Improvement Project, 2018a)
- Guidelines for Preparing O&M Manuals for Dams (Dam Rehabilitation and Improvement Project, 2018b)
- Role and Duties of Dam Warden (Swiss Committee on Dams (CSB), 2015)

If routine inspections have recently been carried out in accordance with national requirements or corporate policy, it may not be necessary to repeat them. Otherwise, guidance such as that of ICOLD provides a good model for the condition assessment of dams.

Among the items that should be covered in routine inspections are the following:

- identification of the legal representative(s)
- identification of the responsible technical expert
- evaluation of the instrumentation available at the dam, indicating the need for maintenance, repair, or procurement of equipment

FIGURE 1.3 | Extract technical diagnosis for major repairs/replacement



- evaluation of any anomalies that may cause failures or malfunctions, including deterioration or defects in the dam and appurtenant structures
- comparison with previous safety inspections
- diagnosis of the level of safety of the dam and appurtenant structures according to the following categories:
  - **normal:** when there are no significant anomalies; routine monitoring is required
  - **attention:** when the anomalies do not compromise the safety of the dam and structures in the short term, but require monitoring, control, or repair over time
  - **alert:** when the anomalies represent a risk to the safety of the dam and structures, requiring measures to maintain safety conditions
  - **emergency:** when the anomalies represent a risk of imminent rupture, requiring urgent measures to prevent and mitigate human and material losses.
- indication of measures necessary to guarantee the dam and structure safety.

Examples of the outcomes from conditions assessment are provided in Appendix B and illustrated in Figure 1.3:

The diagnosis should also include assessment of whether appropriate tools and equipment needed for the proper O&M of the plant are available and in good condition, and an inventory of spares should be produced, including:

- large spare parts (like spare main bearings, spare cooler coils, spare stator windings/bars, field poles, slip rings, breakers, excitation equipment, and possibly spare unit transformer)

- small spare parts and consumables (such as cleaners, coatings, and lubricants, etc.)
- maintenance devices such as stop logs, bulkheads, lifting devices, and trash-rack rakes.

Another approach to condition assessment is illustrated in Case Study 6 of the Salto Grande facility. In this case, HydroAMP methodology has been used to classify the condition of the facility's components, with color coding used for visualization of the results.

1.4 Root cause analysis

Where remedial works are required earlier than expected, it is important to identify why, i.e., the root cause.

Root cause analysis as part of O&M strategy development can determine the reasons for the poor condition of assets and identify areas where improvements are needed, including changes to O&M resources and procedures to ensure sustainable future operations.

Root cause analysis is the process of drilling down to determine the actual cause of failures or poor performance. If the performance of the facility, system, or equipment is not acceptable or in accordance with its designed function, analysis is required to answer the following questions:

- Is the asset being operated, inspected, and maintained correctly as per manufacturer's recommendations and/or internet procedures?
- Is the asset able to respond to changing/updated performance requirements?
- Is the asset unable to meet designed performance due to ageing parts or inherent defects?
- Are other external factors affecting performance, e.g., hydrological variability or transmission constraints?

Analysis should be carried out to determine the root cause of defects, failures, or inability to perform, for critical assets and for noncritical assets, if warranted, on a cost-benefit basis.[6] Analyses of malfunctions and incidents at hydropower facilities indicate the following common causes:

- lack of short-, medium-, and long-term planning for O&M activities
- lack of human capital (number, skills, trainings)
- lack of equipment, tools, materials, spare parts, and testing equipment
- lack of fiduciary resources (including procurement and financial)
- competing interests between operations (production, hydraulic flow, revenues) and maintenance constraints (costs, extended outages)
- inadequate maintenance
- lack of performance measurement
- lack of efficient and transparent governance or national regulations that require reporting
- lack of clarity in O&M procedures, which should include accurate step-by-step operating instructions/procedures and related equipment
- failure to analyze the data recorded during inspection and monitoring to ensure it is within acceptable limits and to identify deterioration trends
- design deficiencies, installation, and manufacturing quality issues.

The root cause analysis should also examine the schedules of inspections and maintenance plans in order to check whether they have been

6 Critical assets are assets whose failure would cause loss or reduction in energy output, a threat to employee and public safety, or damage to the environment. Noncritical asset failures are addressed on a site-specific, cost-benefit basis. The criticality of each asset will vary from facility to facility, and hence critical assets must be identified individually for each facility.

implemented on time, and the results adequately recorded and analyzed. The risks of delays are too often underestimated; the accumulation of lapses and delays in repairs can have potentially serious and cumulative consequences.

The root cause analysis can be extended to review O&M organizational staffing and structures, which can also contribute to poor performance.

1.5 Diagnosis of O&M capabilities, organization, and practices

A key stage in developing an O&M strategy, whether for existing asset owners or developers of new projects, is to assess their capability to carry out O&M services.

For existing owners, a diagnosis of current performance, as described in section 1.1, is an important indicator for capacity to carry out future O&M services. For developers of new projects, examination of the composition, structure, experience, and capabilities of the development team is essential. Where this experience and capability is based on operation of existing assets, the same diagnosis of the facilities they operate and maintain could be adopted, but taking into account the different circumstances of the new project.

A diagnostic review can indicate a low overall level of performance relative to normal industry standards. In the absence of performance monitoring data, a condition assessment will indicate the results of poor O&M procedures and resources. Further analyses can determine whether the problems are due to technical issues (such as poor design or poor quality of equipment), lack of capacity in the organization, or financial or governance issues.

An operational review carried out by experienced hydropower managers or external consultants can map organizational deficiencies that need to be changed or improved. Where poor O&M is observed, an operational audit should take place to determine what changes need to be made to the organization or governance model to ensure proper asset management.

A review or audit of the function of the whole organization helps determine the causes and remedial actions required to facilitate change and inform the longer-term O&M strategy. It should examine operations from a number of perspectives, including:

- the owner/operator's organizational structure, including governance, roles, responsibilities, retention, and recruitment processes
- staff experience, qualifications, and training
- the confidence in and efficiency of the management body
- regulatory settings and impacts (rules, contractual obligations, restrictions, performance requirements, reporting, existence of independent regulatory/controlling institutions, etc.).

The business and regulatory environment often has a significant impact on the function of the organization. Prescriptive regulations, such as those which typically cover dam safety under national legislation, will generally encourage good operating practice. Conversely, environments which encourage risk taking through failure to punish operators, either financially or judicially, can lead to poor practice. Hence the business and regulatory environment can be considered as contributory factors in the root cause analysis.

At the plant level, an operational review would include examination and determination of the adequacy of policies, procedures, processes, and resources involving human resources management, maintenance, operations, financial management, and administrative management and procurement. At both the plant and the corporate levels, the diagnosis should also assess whether sufficient funds have been allocated to the overall O&M program. Expenditures should be compared against the allocated budget, and the work executed should be compared with what was planned.

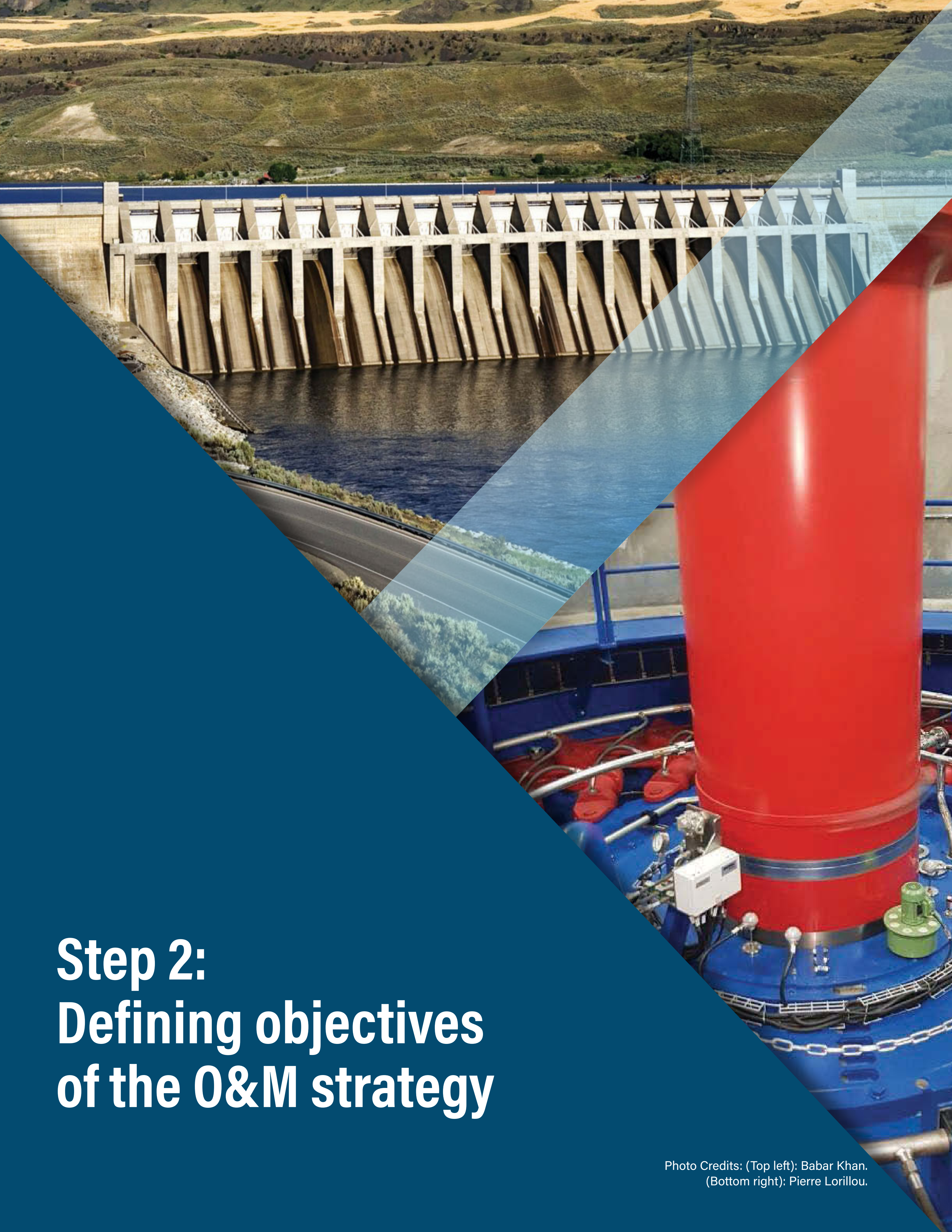
The results of the diagnostic review, the condition assessment, and an operational, organizational, and financial audit may indicate the long-term sustainability of the facility under existing conditions. Where improvements are required, stakeholders need to make changes to eliminate the root causes of poor performance, including changes in the business environment. These changes should be included in the O&M strategy. In particular, when the financial condition of the utility does not allow adequate financing for O&M, preparation of an O&M strategy and associated budget provides the opportunity to demonstrate the need for adequate tariffs or for government subsidies when revenues are insufficient to cover costs.

THE OUTPUT FROM STEP 1

In this first step for preparing an O&M strategy, the diagnosis seeks to (i) identify missing information and required data collection activities to inform the diagnosis, (ii) identify and prioritize key areas of poor performance and those requiring improvements, and (iii) identify root causes of poor performance. The results of the diagnostic reviews in Step 1 allow for a better understanding of the owner's capacity to deliver effective and sustainable O&M and provide insight into the business environment in which the O&M strategy and supporting actions must be delivered.

The outputs from Step 1 include the following:

- analysis of relevant KPIs and root cause analysis for any poor performance
- high-level technical diagnosis on facility condition (for existing fleet)
- review of available/existing human, managerial, and financial capabilities
- organizational/governance audit and recommendations for changes, if applicable
- review of business environment and regulatory issues identified in KPI root cause analysis.



Step 2: Defining objectives of the O&M strategy

Photo Credits: (Top left): Babar Khan.
(Bottom right): Pierre Lorillou.

Based on the issues identified in Step 1, together with a knowledge of good industry practice, Step 2 seeks to define the objectives to be reached through implementation of the O&M strategy.

The objectives of the O&M strategy should reflect the purpose of the facilities, the targets to be attained, and a long-term vision for O&M applicable to each specific organization. Meeting these objectives should be seen as a long-term goal that may require multiple iterations, e.g., changes in the operational management of facilities, short- and medium-term maintenance and refurbishment, or the upgrading of the facilities. In order to ensure that a company's business plan does not become too focused on only one or two performance areas (such as finance or reliability), multiple goals and objectives are required.

2.1 Anchoring objectives in KPIs

Strategic performance objectives of the O&M strategy could be based largely on the KPIs measured in Step 1. The proposed objectives should be:

- **constructive:** aimed at improving performance
- **measurable:** expressed in a quantifiable unit of measurement
- **achievable:** based on available resources (internally or on the market)
- **realistic:** outlined concretely and unambiguously and well-targeted
- **time-bound:** with a start date and an end date, or a cycle (monthly, annual)
- **inclusive:** all stakeholders support achievement of objectives

The objectives of the strategy must be defined by indicators to be applied at all levels, including technical, financial, human resource services, and management, among others. Table 2.1 shows a typical example of a set of objectives. In this instance, the existing performance is inadequate, and a five-year program is envisaged to bring the performance in line with good industry standards.

For each facility, the target range for these KPIs should also be established. The target

TABLE 2.1 Typical objectives of an O&M strategy (for illustration only)

INDICATOR	STEP 1: LEVEL IN YEAR N (DIAGNOSIS)	STEP 2: OBJECTIVES BY YEAR N + 5
Availability factor	70%	95%
Forced outage rate	12%	4%
Number of releases of environmentally damaging products	12	0
Accident frequency rate	5	0

range will depend on the nature, age, location, physical environment, and other factors, and should be achievable if the facility is being operated and maintained in line with good industry practice.

Vision and mission statements may be used, if they exist, or formulated, if they do not, as an anchor point for the O&M strategy. Their primary objective is to communicate the company's strategic goals and is often linked to operational performance. For example, KenGen[7] seeks, "to be the market leader in the provision of reliable, safe, quality, and competitively-priced electric energy in the Eastern Africa region."

The related mission statement from the same East African utility is, *"To efficiently generate competitively priced electric energy using state-of-the-art technology, skilled and motivated human resources to ensure financial success. We shall achieve market leadership by undertaking least cost and environmentally friendly capacity expansion. Consistent with our corporate culture, core values will be adhered to in all our operations."*

Such vision and mission statements only have value if they are used by management as guiding principles for the business.

2.2 Influence of public or private ownership on strategy's objectives

All performance objectives for technical, finance, human resources, security, environment, and other areas are connected to the overarching objectives of the owner. The objectives of public and private owners are broadly similar. However, the approach may depend on whether the owner is a private or public entity, and on whether the organization is commercially driven.

Because they are accountable to their shareholders, private entities may be more likely to embrace the optimization of operations and approaches such as reliability-centered maintenance (RCM). The private owner/operator will typically ensure that the necessary expertise is used to increase efficiency on an ongoing basis, within the objectives and boundaries established in concession agreements and/or other contractual arrangements. For a new entity entering into its first concession arrangement, provision must be made for the procurement of qualified resources to manage the O&M of the facility in order to safely meet objectives, including the objectives laid out in project agreements by the grantor government.

Public utilities, however, may be influenced more by political and governmental objectives, which may guide or constrain the decision-making processes and make it more difficult to implement cost-recovery approaches. Insufficient funding for operating budgets within a vertically integrated utility is often the root cause of the lack of spare parts, materials, tools, qualified employees, procurement of consulting and contractor services, deferral of rehabilitation and upgrading capital, and lack of funding for training, all of which lead to potentially poor operating performance.

The task of formulating the O&M strategy provides an opportunity to examine the performance of the fleet and establish plans to begin a long-term undertaking to restore performance to an acceptable state. In the event of a negative diagnostic outcome for the fleet and utility, improvements can be made to the operator's capacity and changes may have to be made to the business environment.

[7] The public/private power supply utility responsible for the operation and maintenance of the majority of electricity generation in Kenya.

Finally, public and private entities face similar safety and environmental objectives.

2.3 Valuing expected benefits from objectives

Based on the listed objectives it will be possible to estimate the financial value of achieving the improved performance. Such valuation can be derived through preparation of a time series of energy generation and other income translated into expected revenues using assumptions on the potential evolution of tariffs and inflation. It is common for externally funded projects to value the benefits in international currency, such as USD, although other currencies may be adopted. For ease of analysis, the currency used to value benefits should be the same as the one used to value costs.

A high-level benefit valuation should be undertaken for the purpose of defining the O&M strategy. However, more analysis will be required in feasibility studies to prepare detailed cost-benefit analysis, operation plans, and capital expenditure programs.

In order to establish the value of the expected benefits from implementation of the O&M strategy, it is necessary to develop a full understanding of the nature of the revenue and expenditure of the facility (including shared corporate costs).

Revenue enhancement

For an IPP supplying electricity under a long-term PPA, the basis of revenue can easily be established; revenue is most likely derived from energy sales or the availability of power capacity. O&M activities that may enhance revenue can be identified. For merchant IPP plant and utility fleets, revenue generation may be more complex: energy may have different values depending on whether it is firm or intermittent, the time of year, or the time of day. Increasingly revenue will be derived from ancillary services, most of which are based on capacity and the ability to respond to changes in demand. For a facility that is part of a fleet, the issue is complicated further since the benefits may accrue at another asset (which may or may not be a hydropower facility), making it difficult to assign benefits to a specific facility, hence the need to have an integrated vision on the whole fleet (and potentially other assets). Generation from a hydropower facility may complement production from intermittent renewables, enhancing the value of hydro-based production. Beyond real increases in energy generation and related incomes, revenue enhancement also includes the reduction in avoided revenue losses that would (or are likely to) occur in the BAU case (especially due to lower energy generation and/or outages). These avoided revenue losses often represent a very high value that needs to be taken into account in the cost-benefit analysis.

Traditionally revenue enhancement has been based on energy generation, valued at the average selling price of that energy. This simple approach is likely to be adequate for the cost-benefit analysis in Step 7, although a more sophisticated methodology may be used when feasibility studies are undertaken.

Where revenue gains result from rectification of existing defects, or result from restoring KPIs to normal industry levels, the benefits can be predicted with some degree of certainty. However, where the enhancement results from avoidance of failures and defects, a probabilistic approach is required. While complex analysis such as Monte Carlo based modelling has been used for detailed analysis, it is not required for development of the O&M strategy. Simple assumptions may be used for the probability of failure and hence the benefit of avoided failure.

In Case Study 3 on the Kainji and Jebba facilities in Nigeria, the revenue enhancement benefits can clearly be seen (Appendix B). Through implementation of the O&M strategy, including refurbishment, the 482 MW of generation available when Mainstream took over in 2013 increased to 922 MW in 2018, by bringing back into operation units that were out of service. Plans are in place to restore the output to the full 1,338 MW installed capacity within five years, and to enhance this by a further 200 MW.

Cost reduction

Cost reductions can be achieved at the plant, fleet, or system levels. As discussed in the introduction, the cost of repair is much greater than the cost of preventive maintenance. Additionally, with hydropower, there may be opportunities to shut down units for maintenance during low flow periods with little loss of generation. Hence planned maintenance work can be undertaken at greatly reduced costs compared with corrective maintenance.

As with revenue enhancement, the cost-reduction benefits may occur at other assets by avoiding the operation of more expensive generating units (e.g., thermal or nuclear), transmission congestion and losses and purchases from neighboring grids may be avoided. Hydropower, with its ability to ramp quickly and change output frequently, can allow thermal stations to operate at higher efficiency and with reduced maintenance costs. Hence, unavailability of a hydro asset may impose these additional costs on a utility or fleet owner.

Cost reduction benefits are illustrated by Case Study 1 of Statkraft's assets in Brazil, where O&M costs have been reduced by nearly 40 percent at the same time as improving the availability of the facilities.

As well as reduced O&M costs, the avoided costs of failures need to be estimated. These may be contractual (such as liquidated damages or penalties), legal (for example environmental or compensation claims), or physical (the cost of cleanup and restoration).

Nonfinancial benefits

Nonfinancial benefits should be evaluated, even if they will not be used in the financial cost-benefit analysis in Step 7. These include improved corporate image, improved environmental credentials, and reductions in political interference and regulatory control. Improvements in corporate image and credentials can have secondary financial benefits, such as enhanced credit rating, reduced borrowing costs, increased share price, and access to Green Bonds and Climate Finance.

Qualitative criteria, which cannot easily be evaluated financially, may be used in a multi-criteria analysis to evaluate strategies.

THE OUTPUT FROM STEP 2

Will be the time-bound objectives of the O&M strategy, including targeted objectives (with metrics on KPIs), and, if possible, a vision statement. Targets may be of a financial nature (budgets, revenues) or related to production (energy generation), human resources (capacity building and staffing), technical and operational issues (plant O&M performance), health, safety, the environment, other corporate social responsibilities, and any required changes to governance and regulation.

The financial benefits of implementation of the strategy objectives valued in Step 2 are used later for the cost-benefit analysis that will form part of validation of the O&M strategy.

Step 3: Identifying activities for building the strategy

Photo Credits: (Top left): Babar Khan.
(Bottom right): Pierre Lorillou.

In Step 3, the core activities to be implemented by the O&M strategy are identified and prioritized based on the key root causes identified in the diagnosis conducted in Step 1 and on objectives defined in Step 2. The proposed activities for the O&M strategy should also seek, to the extent possible, to eliminate barriers to efficiency as identified in the root cause analysis.

3.1 General considerations

Considerations to be addressed while preparing the list of activities for the O&M strategy should go beyond assessment of asset repairs and refurbishment to examine root causes and long-term and sustainable solutions. In that sense, they should include the following:

1. Improvements in asset management: technical, financial, and human resources management; safety, legal/contractual management; environmental management; social responsibility; and administration should be considered.
2. A "long-term perspective" and sustainable approach to O&M planning and contracts, staff motivation, O&M awareness, capacity building, etc., should be adopted.
3. Management of spare parts must be adequate, and equipment standardized; supplies must be affordable and made available in a timely manner.
4. O&M needs to be funded sufficiently with long-term sustainability in mind, with tariff (and revenue distribution) structures that facilitate sufficient financial resources to cover all costs, combined with good governance free of political interference at all levels.
5. Improvements in training and capacity building are needed in all institutional areas.

The O&M strategy should take a long-term approach covering the full life cycle of the hydropower facility, from commissioning through operations and multiple-life extensions/rehabilitation programs to the end of its useful life at decommissioning or reconstruction.

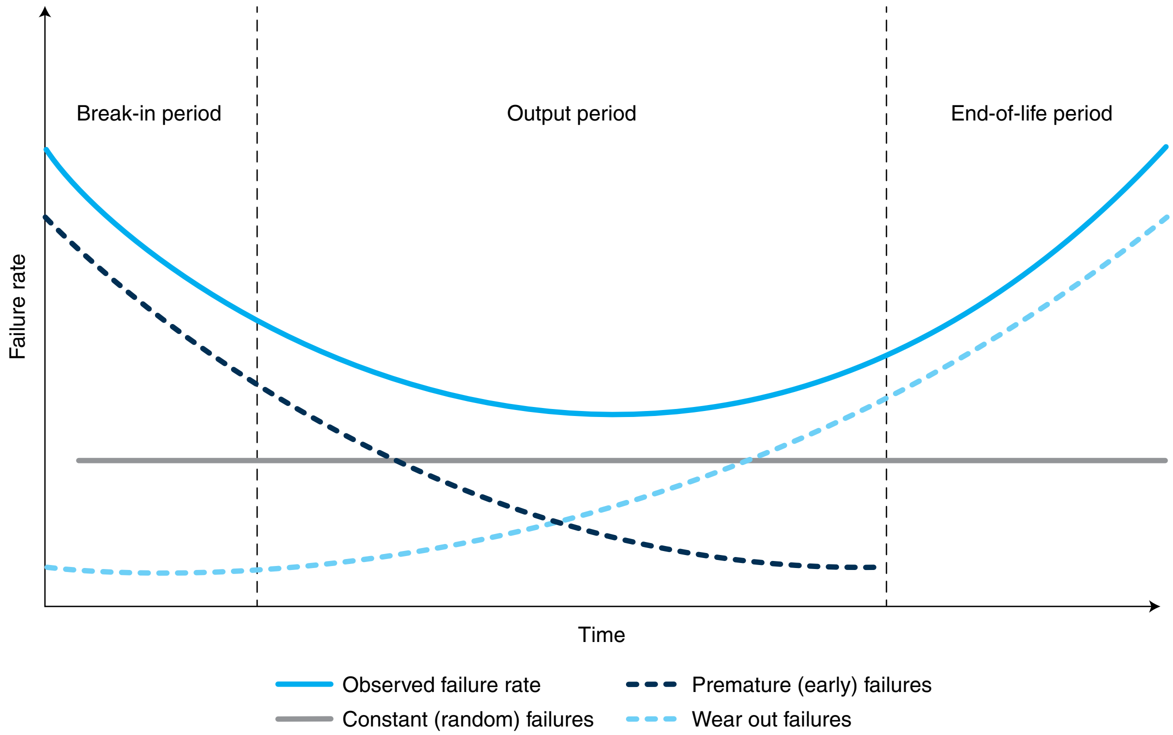
The following sections illustrate the activities that should be covered by the O&M strategy. The list is not exhaustive and should be adjusted to suit conditions specific to the facilities.

3.2 Approaches to O&M

Targeting hydropower reliability

Hydropower facilities typically have physical lifetimes of at least 100 years, thanks to the robustness of civil works and the major generation components. Hydropower generation becomes even more competitive once the capital cost has been amortized. Each component of a hydropower facility has a different lifespan. Civil components are designed and constructed to last 50–100 years, mechanical/electromechanical components have a design life of 20–50 years, and electrical/automation components have a design life of 10–25 years (Flury and Frischknecht, 2012). The longevity of

FIGURE 3.1 | "Bathtub curve" of reliability of typical hydropower over time



hydropower is unique among generating technologies, and the operating life of a well-maintained plant can extend far beyond its design life.

Hydropower facilities should be highly reliable, although the reliability can vary during their life cycle. Like most industrial infrastructure, there is an initial breaking-in period in which any design, material, manufacturing, installation, testing, and commissioning shortcomings manifest themselves in reduced reliability. These issues tend to be resolved over time, and the facility enters a period of relative calm in terms of failures and corrective measures (output period), until it begins to show its age during the end-of-life period. This results in the maintenance life cycle following a "bathtub curve" (Figure 3.1).

In the case of hydropower, the break-in period typically lasts for the first two years of operation, during which most "teething issues" are resolved. This period is typically covered by the equipment supplier's warranty and the defects liability period of the contractor. The output period, during which low failure rates are observed, should extend over a period of decades. The end-of-life upsurge in failures can be avoided if the plant is maintained in good order and components are replaced before they start to fail.

Operation of hydropower facilities

Hydropower operation is a continuous activity that requires qualified staff and management to ensure that the plant or fleet is operated in accordance with its design, with the applicable agreements, licenses, laws, market rules, and regulations, to meet the needs of the energy system. If the facility or fleet is owned by an independent power producer (IPP) as a concessionaire, it will additionally be governed by the concession license and operating agreement, the requirements of PPAs and by commercial considerations.

Each hydropower development is unique in design, reflecting the site location, the type of ownership, and the purpose of each facility. This uniqueness poses challenges for owners and operators who must create a unique strategy and set of operating procedures for each facility.

A critical responsibility of the operating staff is for control of reservoirs and downstream flows for day-to-day generation and during flood events. Traditionally reservoirs are managed using "rule curves" to achieve optimal benefits. However, these rules are often developed during the feasibility study, and may not have been altered to take account of changes to the hydrological regime, revised operating role of the hydropower facility, multipurpose usage, and changed values of water and energy. Modern approaches to reservoir operation, including use of real-time remote telemetry, are discussed in section 3.6.

Such operation should comply with a comprehensive dam safety program, and emergency preparedness plans should be in place in the event of an emergency arising. These dam safety aspects are not addressed in detail in this note since guidelines are already available on dam safety.

Maintenance of hydropower facilities

Maintenance encompasses the activities carried out to ensure safe and reliable operation of assets to meet their designed purpose and the required performance on a continuous basis. The maintenance program of a hydropower facility seeks to maintain assets in a manner that maximizes availability and reliability at an optimal life-cycle cost, while protecting employees, the public, and the environment. The cost of a maintenance program needs to be appropriately allocated to ensure the right balance between the potential risks and avoided costs, weighed against the risks of unavailability and safety if the work is not carried out. The cost of maintenance includes not only labor, materials, and equipment, but also the cost of outages to perform the work, including lost generation and lost revenue.

In Table 3.1 a progression of increasingly sophisticated approaches to O&M is illustrated. While the more sophisticated approaches may not be warranted for all facilities, in most cases moving to at least Level 3 can be justified, in order to maintain good plant performance and conditions at low cost.

TABLE 3.1 | Approaches to O&M

LEVEL	DESCRIPTION	APPROACH	CONSEQUENCES
1	Reactive/corrective maintenance	Maintenance and repairs are carried out when failures occur, or when components are observed to be degraded, sometimes using cannibalized parts.	Outputs and revenues are lost, assets degraded, and lifespan shortened. In worst cases, plants cease to operate.
2	Routine/preventive maintenance	Maintenance is carried out in accordance with manufacturer's instructions, and replacements are made after specified running hours.	Plants achieve average availability at average costs, in line with common industry practice.
3	Condition-based maintenance	Condition and probability of failure are assessed.	Plant is maintained in good condition, with good operating efficiency at low O&M cost.
4	Revenue and risk- based maintenance	Revenue loss events are identified, probability calculated, CAPEX/OPEX plans compared using risks/cost/benefit analysis or reliability-centered maintenance (RCM) methodology.	Revenue is maximized at low O&M cost, with reduced risk of revenue loss, and the life of physical assets is preserved.
5	Holistic PAS55/ISO55000	Holistic approach to asset management covering organization, qualifications, training, corporate and social responsibility (CSR), monitoring, and reporting.	Best-practice approach to O&M: optimal revenue/cost balance and life preservation, with robust practices, providing investor and stakeholder confidence.

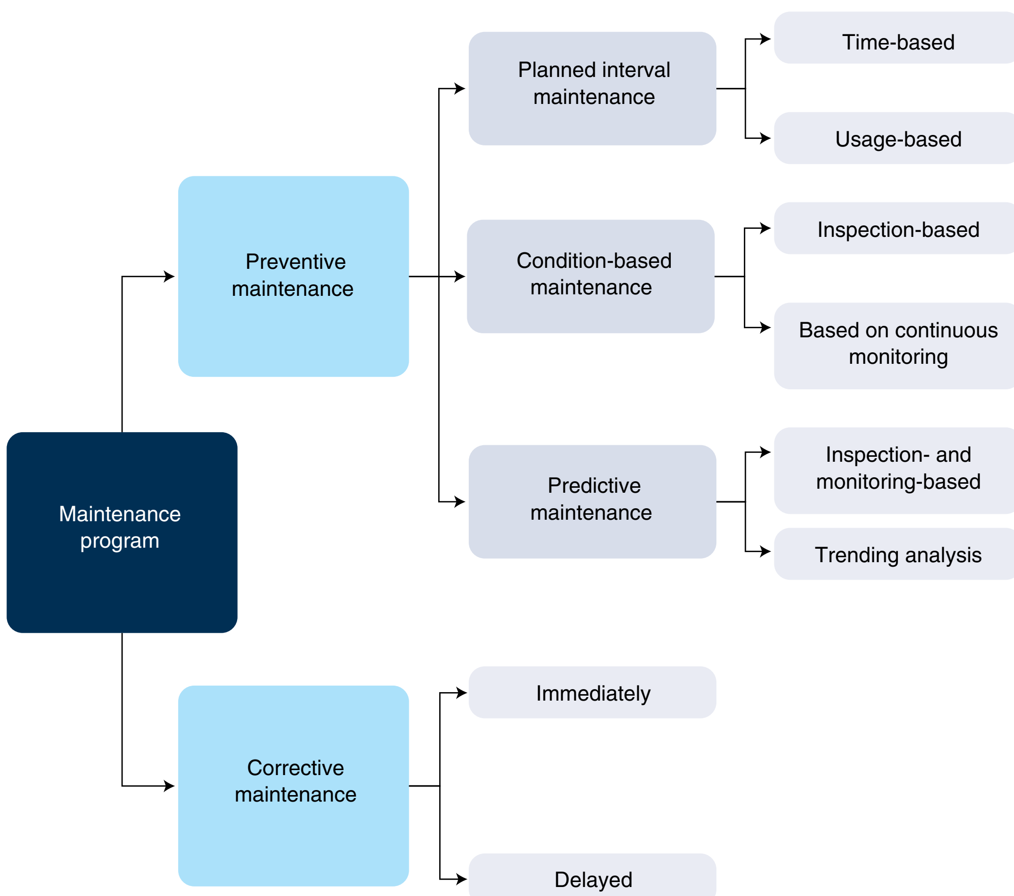
3.3 Selecting the appropriate maintenance approach

Finding the right balance between maintenance costs and acceptable risks is unique to each installation and requires the seasoned judgment of hydropower O&M staff and advisors to design a specific program appropriate for each situation.

As shown in Figure 3.2, and described further below, there are a range of different approaches to maintenance.

- **Preventive maintenance:** Maintenance activities are planned and carried out preemptively, to reduce the likelihood of failure and to prolong the useful life of the equipment. Preventive maintenance may require a physical examination of the equipment being inspected and maintained or tested, normally requiring some dismantling and reassembly while out of service. Record keeping and analysis of findings are essential in helping establish optimum intervention periods and actions to be taken during future maintenance outages. One of the frequent risks involved with preventive maintenance activities is the failure of the equipment following a maintenance intervention as a result of human error in performing the maintenance work. Preventive maintenance is made up of various approaches (to determine the timing and extent of maintenance interventions) that include the following:
  - **Planned interval maintenance:** Maintenance activities are carried out on a time schedule or triggered in accordance with an equipment-usage schedule. This has been the traditional approach to maintenance and is included in O&M plans produced during a facility's commissioning.

FIGURE 3.2 | Types of maintenance included in a maintenance program



- **Condition-based maintenance:** Maintenance is based on the results of inspections, alarms, and the monitoring and analysis of the behavior of equipment and structures during normal operation. Where degradation of equipment is likely to lead to failure or inefficient generation, maintenance, repair, and refurbishment measures are deployed.
- **Predictive maintenance:** This approach makes use of condition monitoring data and trending analyses to predict the likelihood and timing of potential failures. Failure prediction uses condition assessment data and test results obtained during outages as well as continuously collected monitoring data. Modern plants employ online, real-time monitoring of equipment, systems, and civil structures (movement, leakage, etc.) to provide data which are used to plan and continually fine-tune the preventative maintenance program.

- **Corrective maintenance:** After a failure, corrective tasks (including repair and replacement) are carried out to return an asset to a state in which it can perform as required. In this approach, maintenance of selected assets can be planned under a run-to-failure model (usually with appropriate spares in stock), where preventive maintenance is not justified on a cost-benefit basis. Corrective maintenance, which is often estimated to cost three to six times (Ogaji, Eti, and Probert, 2006) as much as planned, preventive maintenance, should be minimized by an effective preventive-maintenance program. Run-to-failure strategies should then be coupled with pre-purchase (or pre-procurement) of spare parts to avoid long forced outages.

Hydropower owners have been migrating toward reliability-centered maintenance (RCM) approaches for the past 25 years, as a follow-on to the adoption in the early 1990s of Computerized Maintenance Management Systems (CMMS). RCM, which is a predictive maintenance methodology, had its beginnings in the airline industry and is now being deployed in other industries, including power. The design of a RCM program is based on comparing the cost of maintenance against the consequences of failure, including revenue loss and the cost of repairs. RCM seeks to optimize this balance by applying the right amount of maintenance resources to achieve the desired level of reliability. However, allowance needs to be made for noneconomic failure modes, where cost is not the only determinant, e.g., hazards that may increase the risks of failures that could result in violations of regulatory statutes or could cause harm to employees, the public, or the environment.

An effective maintenance program is designed around the principles of preventive maintenance, and it includes timely response to corrective maintenance required at the site. RCM is the ultimate goal but requires a well-established maintenance program. Therefore, the RCM principles should be strongly considered when preparing an O&M strategy.

Reinforcing routine inspection and maintenance

Routine inspection and maintenance could be reinforced during the strategy development process, especially when the diagnosis demonstrates weaknesses in this area.

Routine inspections and maintenance should be carried out on a regular basis in accordance with a time schedule or a run-time schedule. These schedules are typically prepared prior to commissioning and should be updated regularly after commissioning.

The schedules will detail the frequency of inspection, testing, and maintenance of each component of the hydropower facility. Typically, there will be an annual schedule that will show the timing of activities required on a daily, weekly, quarterly, and annually basis, and a long-term schedule, which shows the timing of less frequent activities such as tunnel dewatering and equipment dismantling. The schedules are accompanied by record sheets and forms to be used during inspections, maintenance, and repair activities. Further guidance on the preparation of O&M plans is given in Step 8.

The schedules indicate the minimum frequency of inspections and maintenance. Frequency should be increased following unusual events such as extreme flood flows, earthquakes, heavy rainfall, and use of equipment outside of normal operating range, e.g., increased starts/stops. Following such unusual events, special safety inspections should be undertaken to evaluate any damage, and to establish actions required to restore the security level of the facility.

It is important that parameters are not only recorded, but also analyzed. Abnormal readings and deterioration trends should be investigated. It is therefore important that operators understand the significance of the parameters and are aware of the normal range of readings.

3.4 Planning repairs and refurbishments

The choice between maintenance, repair, overhaul, or replacement of hydropower components is an important asset management question since it may significantly impact the cost of the proposed O&M strategies and plans. The choice should be carefully reflected in the long-term planning of outages, O&M budgets, and CAPEX plans. The first step in assessing the need for maintenance or replacement is to understand the life-cycle cost of hydropower equipment or other assets. A life-cycle cost analysis analyzes the cost of a system (or a component) over its life span. Typical costs for a system may include the following:

- acquisition costs (design and development costs)
- operating costs
    - failures
    - repairs
    - spare parts
    - downtime
    - loss of production
- maintenance costs
    - corrective maintenance
    - preventive maintenance
    - predictive maintenance
- capital rehabilitation costs
    - major replacement and life extension of equipment
    - engineering, environmental impact assessment and lost production
- disposal/dismantling costs.

The life-cycle cost is equal to (i) the initial (projected) capital costs plus (ii) the projected lifetime operating and maintenance costs plus (iii) the projected capital rehabilitation costs plus (iv) the projected disposal costs minus (v) the projected residual value (e.g., residual infrastructure such as dams, reservoirs) (WERF, n.d.).

Life-cycle costing is critical when deciding whether to maintain and repair or to replace hydropower equipment. Rarely is it financially viable to replace equipment ahead of its end-of-life unless it has failed or there is a requirement for additional capacity or capability. In most cases, it is more economic to maintain and repair in order to extend the life as long as possible. Table 3.2 includes criteria designed to help users make decisions on whether to repair or replace equipment. If the majority of answers to the questions is “yes,” then replacement may be the preferred option.

TABLE 3.2 | Checklist for deciding whether to repair or replace

ITEM	YES/NO
Equipment is near or beyond its expected life.	
Equipment reliability and the consequences of unplanned failure pose unacceptable risks or unacceptable costs (loss of energy and revenues).	
The repair/refurbishment costs exceed the life-cycle cost of the equipment replacement.	
The asset's performance has been unacceptable, and corrective maintenance measures will not lead to acceptable performance.	
Existing equipment is technologically obsolete, spare parts are expensive or hard to get, and the skills needed to properly repair and maintain are hard to find.	
Existing equipment poses an unacceptable security, health and safety, or environmental risk, and the cost to mitigate the risk exceeds the asset life-cycle replacement cost.	

Source: WERF (n.d.).

If the replacement assessment is positive in terms of net present value, the equipment/asset is added to the capital improvement program. An additional risk assessment or prioritization complements the replacement assessment to determine the timing of remedial work compared with other capital projects.

Considering the large capital costs and large potential impact on revenues (direct from generation and indirect due to outages), this analysis (associated with planning of outages linked to maintenance and capital works) will require highly-skilled resources, with technical, scheduling, and economic backgrounds. It will also require refined comparative economic analyses of different scenarios.

An output of this exercise should be a list of major repair and replacement activities that represent major financial expenditures but that make sense economically, environmentally, legally, or in terms of safety, together with tentative dates for implementation and necessary preliminary studies and procurement processes. They will be taken into account while further developing the O&M strategy.

3.5 Improving or upgrading the operation of facilities

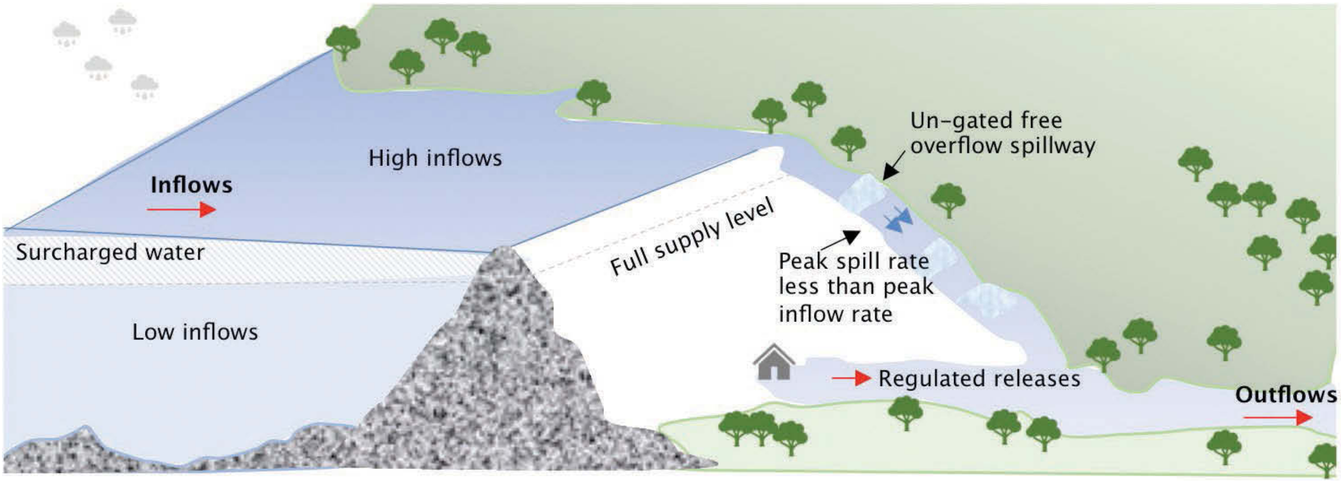
There may be a wide range of options for improving, upgrading, or repurposing facilities that can be considered when establishing the strategy. Advances in technology, changes in the power system and increased awareness of environmental and social impacts and climate change present opportunities and challenges that should be addressed in the strategy. Some of the areas that may be considered and enhanced are described below.

Enhancing peaking capacity and ancillary services

Hydropower generating facilities contribute significantly to grid reliability in term of energy, capacity, and ancillary services (Key and Rogers, 2013). Hydropower provides many ancillary services, including dispatchable generation, reactive power and voltage control, frequency control, and operating reserves. These ancillary services support the grid and allow integration of variable renewable energy (VRE) into the overall power system. Understanding the peaking and ancillary potential of the hydropower facilities is therefore recommended for quantifying the value of hydropower generation and to assess potential future development and optimization.

Even hydropower facilities with relatively small reservoirs can provide peaking support to the grid by operating at high output during peak hours and either reducing output or completely shutting down during off-peak hours (while minimum environmental flow is still released). Increasing peaking capacity requires hydrological studies, as well as socio-environmental assessments to determine upstream and downstream impacts (especially linked to discharge gradients and potential safety risks for population). In

FIGURE 3.3 | Operation of a hydropower reservoir



Source: Australian Government (2019), https://www.mdba.gov.au/river-murray-system/running-river-murray/flood-management-dartmouth-dam

cascading hydropower facilities, peaking can be implemented at the upper site, with the lower site acting as a re-regulating reservoir and thus reducing downstream impacts.

Typically, the spot pricing of power is highest during peak hours. Hence the benefits of providing peak power are likely to include higher revenues and support to the grid. Detailed hydrological, market, and financial analyses are required to optimize the selection of such option.

Optimizing reservoir operation

The purpose of hydropower reservoirs is to store water to control energy production over time. Simulating reservoir inflows is important in order to assess the full range of inflows into the reservoir and when storage is being utilized to meet the required outflows (Figure 3.3). Inflows are usually calculated from changes in storage volume and total outflows using the water balance equation. The accuracy of the inflow calculation is directly dependent on the reservoir storage volume estimation, measured outflows, and water elevation measurement in the reservoir. Operating a facility within the prescribed operating rule curves requires the calculation of daily inflows and forecasts of weekly and monthly inflows.

Increasingly, hydropower operators are employing remote telemetry to transmit meteorological and hydrological data from the reservoir catchments to provide inflow data. The data can be used to augment data from the hydropower site to provide up-to-date records for planning operations and for developing new rule curves. However, it can also be used in real-time to program generation, thereby optimizing the use of the available water.

Reservoir optimization studies can be performed (or at least recommended in the strategy) to more accurately predict short- and long-term inflows, optimize power generation for meeting domestic demand whilst maximizing export revenues, improve flood management, and balance multipurpose use of the reservoir by meeting environmental and social obligations. These obligations should include the ecological flow releases defined in the environmental and social management plans, operating licenses, and national legislation.

A useful methodology to establish whether reservoirs are being operated well is to run a reservoir power and energy simulation model such as HEC-3 (USBR) using actual historic hydrological data and to compare the simulated electricity output with the actual generation over that same period. This will indicate whether the theoretical output is being achieved, and analysis of the results can indicate whether any shortfall results from operational or maintenance deficiencies.

Among the guidelines available to assist with operation of hydropower reservoirs is ICOLD's Bulletin 173-2016: Integrated Operation of Hydropower Stations and Reservoirs. Update of reservoir operation rules should also be informed by dam safety analysis and based on FEMCA (failure mode effects and criticality analysis) and PFMA (Potential Failure Mode Analysis). Reservoir operation should also be supported by an early warning system.

Optimization software or decision-support systems (DSS) can help determine long-term storage planning and management, short-term (hourly-time resolution) scheduling, and real-time dispatch.

The benefits of using such a system include the following:

- increased energy production and revenue from reservoir and plant-operation optimization
- improved automation of work processes
- improved safety and reduction in the risk of costly flood-damage repairs
- increased returns on new capital investments
- effectiveness in dealing with environmental issues and improving public image
- reduction in operational and business risks.

Therefore, preparing an O&M strategy could provide an opportunity to review existing reservoir management and review optimization and automation options.

Environmental and social aspects

As part of the preparation of the O&M strategy, it is recommended to follow good international practice for environmental and social management of hydropower plants during operations. The O&M strategy will benefit from compliance with the protocols and guidance of the WB's environmental and social framework (ESF) and its environmental, health, and safety guidelines[8] to build and operate sustainable hydropower.[9] The O&M strategy could in particular benefit from compliance with the following environmental and social standards (ESS):

- EES1 on environmental and social assessment of impacts and risks
- ESS2 on labor and working conditions
- ESS3 on resource efficiency and pollution prevention and management
- ESS4 on community health and safety
- ESS5 on land acquisition and involuntary resettlement
- ESS6 on biodiversity conservation and sustainable management of living natural resources
- ESS7 on indigenous peoples
- ESS8 on cultural heritage
- ESS10 on stakeholder engagement and information disclosure

Social inclusion is a key aspect of facility management, contributing to smooth and efficient operation of the hydropower plant. Compliance with the ESF, and in particular ESS2, ESS4, ESS7, and ESS10, will help to improve social relationships between the facility owner and local communities. Benefits accruing from good community relationships include worker satisfaction, social cooperation, and potentially support in achieving environmental and social obligations,

[8] https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/policies-standards/ehs-guidelines
[9] https://www.worldbank.org/en/projects-operations/environmental-and-social-framework

such as ecological flows, biodiversity protection, and catchment management.

Compliance with environmental and social guidelines and sustainability protocols is playing an increasingly important role under corporate and social responsibility (CSR) in corporate governance. While access to finance for the private sector has for many years been contingent on compliance with environmental and social standards, such as the International Finance Corporation (IFC) performance standards and the equator principles, there is increasing pressure for improved social responsibility from other sources. It is increasingly common for employees, investors, consumers, service providers, and suppliers to consider CSR performance as drivers in their relationship with companies.

Adaptive management methodology may be employed, especially for catchment and ecosystem management. During operation, the environmental and social management plan (ESMP) prepared prior to construction must be updated and fine-tuned for the operation stage through an interactive process with regulators (environmental license and water permit regulators), monitoring, analysis, and learning, so that the ESMP are progressively adjusted to achieve the agreed outcomes (such as ecological flows, offsets, watershed management plans, benefit sharing schemes, etc.).

The O&M strategy may also benefit from the guidelines in ICOLD Bulletin 159-2012: Dams and the Environment from a Global Perspective.

Climate resilience

When planning improvements to the facility and its operation, consideration should be given to the potential impacts of climate change. Guidance on this aspect is available from sources such as ICOLD's Bulleting 169: Global Climate Change, Dams Reservoirs and Related Water Resources. Specific Guidance on adaption and resilience of hydropower facilities is available from the Hydropower Sector Climate Resilience Guide published by IHA (International Hydropower Association, 2019). Increasingly, a Climate Resilience Management Plan will be required by lending institutions in support of funding applications for major CAPEX programs.

Enhancing watershed management

Reservoir management is a subset of overall watershed management. Watershed management is an adaptive, comprehensive, and integrated multi-resource management planning process that seeks to balance safety, ecological, economic, and cultural/social conditions within a watershed. Watershed management serves to integrate planning for land and water. It takes into account both ground- and surface-water flow, recognizing and planning for the interaction of water, flora and fauna, and human use (for example, agriculture in the catchment and recreational use of the reservoir) found within the physical boundaries of a watershed. This approach is also likely to further enhance acceptance of a hydropower facility in the local, environmental, and socioeconomic context.

It is important that the O&M strategy is reviewed when upstream or downstream hydropower schemes are developed on the same river, to ensure that any interaction between facilities is taken into account, and that safety and operating efficiency is maintained.

Sediment management

For run-of-river hydropower facilities or reservoirs that have limited storage capacity, sediment management in some regions is particularly important and may be revisited in preparing a strategy. The forebay/head pond is generally cleaned during a high flow period by shutting down the turbines and flushing the sediment by drawing down the head pond and/or by manual dredging. It is important to follow environmental regulations related to water quality during the sediment flushing process. The reduction in sediment in the forebay helps to minimize sediment entry into the headrace, reducing wear on the penstock and turbine components.

For facilities where sediment is identified as a major issue, initiatives such as upstream sediment traps or watershed management may be explored for reducing sediment in rivers to reduce premature failure of the turbine runners and associated equipment. Not addressing the sediment problem may otherwise reduce the benefits of any future rehabilitation and life extensions.

For hydropower facilities with larger storage, it is important to have a sediment management plan to ensure the long-term management of the reservoir with respect to storage capabilities and operation of the powerhouse and associated discharge structures. For existing facilities, bathymetric and water quality data will be mobilized to estimate the total volume of sediment and determine an average rate of sediment deposition. Sediment management measures include options to remove or flush out the sediment in a safe manner based on data collected during field investigations (sediment volume, distribution, and grain size). Dredging might be considered if other measures are not viable.

It is also important to maintain low-level outlets of the dams to flush sediment on a regular basis, since failure of low-level outlets could compromise dam safety and lead to larger sediment problems.

Guidance on sediment management in reservoirs is available from various sources such as ICOLD and IHA,[10] and from WB's publication: *Extending the Life of Reservoirs: Sustainable Sediment Management for Dams and Run-of-River Hydropower* (Annandale, Morris, and Karki, 2016).

Ecological/compensation flows

Hydropower dams are generally required to pass environmental flows *(e-flows)* which are often embodied as part of environmental and social management plans (ESMPs), environmental licenses, and national legislation. E-flows are indeed fundamental to maintain basic river characteristics and functions and to provide some habitat for biodiversity and for social and cultural needs. There are many methods to define e-flows (Tharme, 2003) and the O&M strategy will benefit from review of the e-flows adopted in the initial design. The WB and other agencies have prepared numerous guidelines on e-flows.[11]

Historically e-flows were seldom used for generating electricity. The installation of low-impact micro-turbine generation (MTG) technology in regulating dams to generate power with e-flows can also provide a beneficial use of this resource. The MTG turbines are fitted with a bypass valve so that the e-flows are never interrupted as a result of power rejection or turbine shutdown. For example, the Reventazón hydropower plant (315 MW) located in Costa Rica installed an additional turbine and powerhouse at the foot of the dam to use the e-flow to increase the installed capacity of the project. Another example is the installation of the 450 kW MTG turbine in a rock-fill dam in Ontario, Canada, which provides an additional 3.9 GWh of energy generation (Picmobert, 2016).

Replenishing and improving management of spare parts

The diagnosis carried out in Step 1 may indicate a requirement to restore stock levels of spare parts and to establish a process and tools to measure and manage stock movement according to the first-in, first-out principle (FIFO). Procurement for replenishment of spare parts should also be carefully planned and implemented. It should

[10] https://www.hydropower.org/sediment-management
[11] http://documents.worldbank.org/curated/en/372731520945251027/pdf/124234-WP-Eflows-for-Hydropower-Projects-PUBLIC.pdf; http://siteresources.worldbank.org/INTWAT/Resources/Env_Flows_Water_v1.pdf

be checked during the assessment whether a maximum and minimum quantity is set for every stock item (a number below the minimum will generate a re-order action to replenish the stock). Tools to be mobilized can include an enterprise resource planning (ERP) tool such as SAP. For small facilities, business accounting software that can handle inventory management could also be considered. Inventories could be made available to staff within the owner organization and confirmed during annual inventory taking.

If there is no ERP or stock management tool available, the process can be undertaken manually by stores and maintenance personnel, as has been traditionally carried out.

3.6 Modernizing existing facilities

There are many opportunities for modernization of hydropower facilities that can be explored during feasibility studies for refurbishment and life extension of equipment. This subsection includes some, but not all, opportunities.

Further automation of operational planning, dispatch, and control

Daily operation of a hydropower facility was traditionally undertaken by staff on site who had responsibility for starting, stopping, and varying the power output in accordance with instructions from the system operator. The station operators declare in advance the availability in terms of number of units, power output, energy available, planned outages, and other constraints such as environmental limits on cycling and downstream limits on flow changes, etc. Such declarations may be required weeks or months in advance for planning purposes and are progressively refined as the dispatch time approaches.

Utilities will have their own procedures for these declarations, and the operation will also be covered by the grid code. In the case of IPPs, the procedures should be clearly defined in the PPA and will also be subject to the grid code. The procedures will allow for emergency control where changes to the planned dispatch are required due to events within the facility or on the power grid.

Many hydropower facilities are operated on the basis of "rule-curves," where the declared availability is based on the water level in the reservoir and time of year, or the actual river flow in the case of run-of-river facilities. Rule curves are established based on historic hydrological records and targeted seasonal generation patterns and were formulated prior to commissioning the facility. In many cases, the rules have not been updated to reflect better understanding of the hydrology, including climate change impacts, changes to the power system, and the role played by the hydropower facility compared with other generators. Improved optimization and new approaches to operation are discussed in the following sections.

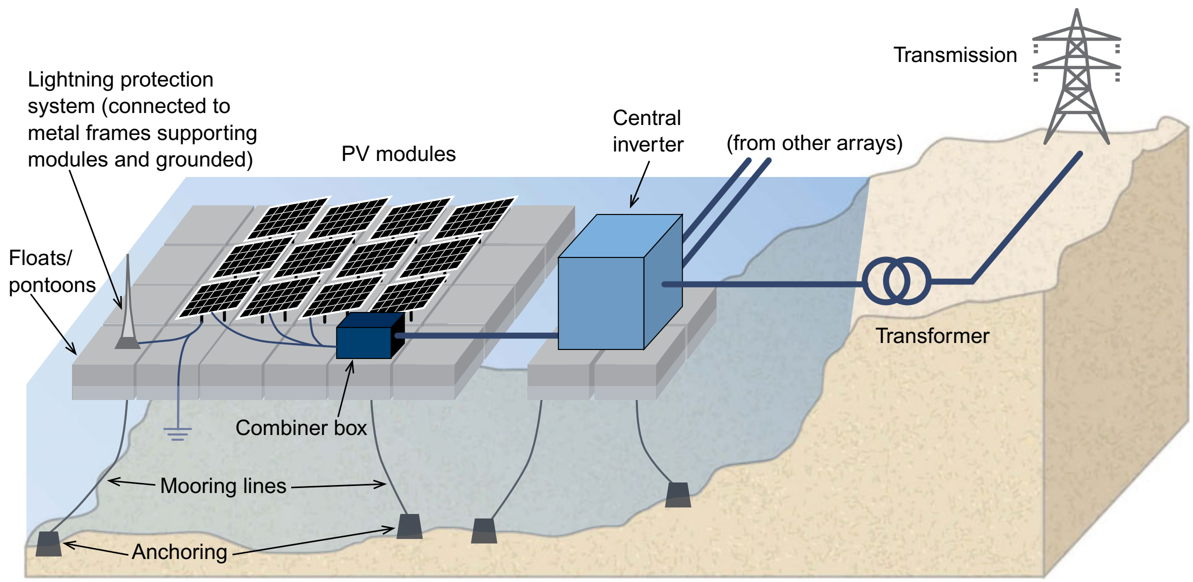
Increasingly, with automated facilities and remote control of new and refurbished plants, these functions are performed centrally, either for a group of stations or for an entire fleet.

Computerized maintenance management systems

Installation of and training through a computerized maintenance management system (CMMS), such as the one used by Statkraft in Case Study 1, is another opportunity for modernization. CMMS is a software designed to simplify the management of maintenance. Historically, data were recorded manually, and maintenance, largely reactive rather than proactive, was performed only when something went wrong.

With computerization, it has become possible to track work orders, generate accurate reports, and instantly determine which assets require preventive maintenance, reducing maintenance costs.

FIGURE 3.4 | Floating solar plant setup



Source: ESMAP (2019).

The cost of implementing, operating, and maintaining a bespoke CMMS is relatively high because of the customized nature of the software. Standardized cloud-based solutions can also be considered since they have a reduced purchase price and are generally hardware independent, providing a lower-cost solution for asset management.

Floating or hydro-connected solar plant

A floating solar plant is an array of solar panels on a structure that floats on a body of water, typically a reservoir or a lake, as illustrated in Figure 3.4. The power generated from the floating solar plant can be transmitted to the grid using an existing hydropower substation, saving the cost of separate interconnection. Floating solar is a relatively new concept. Its benefits include reduction of evaporation in the reservoirs, which could be important in large reservoirs in hot and dry climates.

World Bank's ESMAP (Energy Sector Management Assistance Program) has been investigating opportunities for installation of floating solar equipment.

About 1.5 hectares of reservoir area are typically needed to set up a 1 MW floating solar plant (Pickerel, 2016). Many factors might affect this requirement, such as the type of floats being used and the distance from the shore for electrical design aspects.

Solar land development on the vicinity of the hydropower facility (hydro-connected solar) can also be considered as another option to benefit from available land, and existing substations, lines, supervisory control and data acquisition (SCADA), and human resources.

3.7 Integrating O&M in the design of new projects and major refurbishments

There is a trade-off between initial capital expenditure and the cost of O&M. Typically a high-specification design with high-quality construction and equipment will cost less to operate and maintain, last longer, have fewer outages, and produce more energy.

There are many aspects to designing for ease of operation and maintenance and reduced O&M

costs, which need to consider the specific conditions of the facility. A few are listed below:

- Adequate room in the loading bay and around the units needs to be provided for dismantling, laying out equipment, and reassembly.
- Adequate head room below the crane in the turbine hall may enable the turbine-generator units to be removed without splitting the shaft, avoiding time-consuming alignment and balancing procedures during maintenance.
- For Kaplan units in conditions where erosion is likely, the ability to remove blades individually from below can substantially reduce the maintenance time and cost.
- Redundant systems can allow one set to be maintained or replaced while the facility is still operating.
- Use of multiple units can allow maintenance outages during low-flow seasons without loss of generation, where a single unit would require a full station shutdown.

Designs should also consider the safety and the risks of failure during O&M. Examples include:

- Provisions should be made for double closure (gates and stop-logs) to provide safe work conditions.
- Pipes or openings to the high-pressure side of the waterway, including pressure-sensor openings and pressure-balancing pipework present a risk of flooding and should be avoided or protected by valves.

Sediment management is an area where a balance must be struck between capital and operating costs. Desanding facilities often have a high capital cost, especially in mountainous regions where sediment is often a major consideration. Undersizing or not providing desanding chambers may result in rapid erosion of runners, leading to loss of efficiency and high repair costs.

The method of optimization of the project at the feasibility stage can affect the construction cost-OPEX trade-off. Economic modelling using a low discount rate will tend to favor initial expenditure to avoid future costs. However, economic modelling using a high discount rate, or financial analysis using a high cost of capital tends to devalue future costs and revenues, favoring low construction cost facilities.

Similar issues are encountered with quality. Low specification, low quality equipment, or poor construction may be favored by financial optimization but will have consequences for O&M in the future. This is one of the challenges noted by the operators of Salto Grande in Case Study 6. Although the initial equipment installed 40 years ago was of high quality, enabling prolonged operation at a high level of availability and at a low cost, there is concern that financial drivers may encourage procurement of cheaper, low-quality equipment, which might make the current O&M strategy unviable.

3.8 Selecting adequate quality standards

Although there is no specific standard for hydropower O&M that is publicly available or universally adopted, standards are available for hydropower procurement, construction, installation, and commissioning of civil, electrical, and mechanical equipment. Some of these standards can provide further strategic guidance for various aspects of O&M. They include the following:

- IEEE 492-1999, IEEE Guide for Operation and Maintenance of Hydro-Generators
- IEEE 1147-2005 (R2012), IEEE Guide for Rehabilitation of Hydroelectric Power Plants
- FDX 60-000–ICS: 03.080.10–AFNOR (2002), Maintenance Services/Facilities Management
- ISO 55000:2014, Asset Management: Overview, Principles and Terminology

- ISO 55001:2014, Asset Management: Management Systems, Requirements
- ISO 55002:2018, Guidelines for Application of ISO 55001

ISO 55000 is becoming a recognized and universally accepted asset management standard. It is starting to be adopted by public and private utilities around the world, such as Swiss company Alpiq (Rouge and Bernard, 2016), that have a fleet of assets and are looking to manage the whole life-cycle of the hydropower asset. Implementation of asset management standards can result in improved operational performance and asset condition, a high plant availability factor, and efficient and reliable operations.

THE OUTPUT FROM STEP 3

Includes identification of the core activities and measures required in order to achieve the strategic objectives established in Step 2, based on the diagnosis completed in Step 1.

Step 4: Exploring strategic models for implementing O&M strategy

Photo Credits: (Top left): World Bank.
(Bottom right): Pierre Lorillou.

In Step 4, various strategic models for O&M are explored. After describing the main features of each model, strengths and weaknesses are compared, and guidance is provided as to which model is most appropriate in which contexts. The key features of O&M contracts are then examined.

4.1 Types of O&M strategic models

Three types of models can be mobilized to implement an O&M strategy:

- Model 1: Owner retains sole responsibility for O&M
- Model 2: Owner outsources some O&M responsibilities to consultants, contractors, or suppliers
- Model 3: Owner outsources all O&M responsibility to an independent operator.

Model 1 will generally be the preferred option where the owner has the skills, resources, and capability to undertake O&M, which also aligns interests of O&M teams with those of the owner. Model 1 is seen as the ultimate goal, while Models 2 and 3 can be broadly considered as interim arrangements.

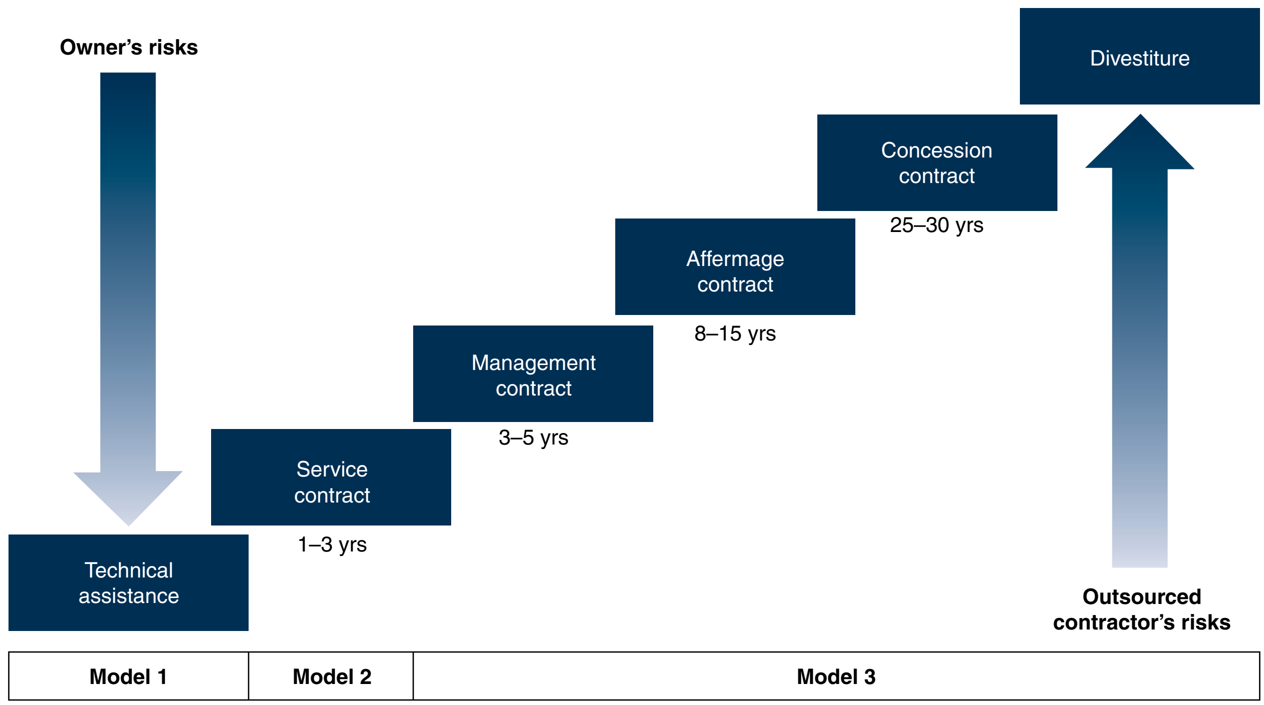
If Model 1 is inappropriate due to the owner having insufficient skills, resources, or capability, and technical assistance is unlikely to raise performance to adequate levels, further options for enhancing private sector participation (PSP) in the delivery of O&M services may be explored. Each option allocates risk differently between the private party and the owner. Risk allocation should be based on the principle that risks are assigned to the party best able to manage and bear them. These options are explored in Models 2 and 3. As illustrated in Figure 4.1, moving from Model 1 through Model 2 to the various options of Model 3 progressively transfers risk to the outsourced contractor, reducing the owner's risk but often increasing overall costs.

However, irrespective of the model adopted, the owner will generally carry the ultimate responsibility for external risks such as safety, environmental performance and compliance with regulations, legislation, and contractual obligations.

In some cases, models may overlap. For example, under Model 1, although the owner is fully responsible for O&M, he will often commission studies and advisory services to support the O&M function, or to evaluate refurbishment and upgrading options. The boundary between Model 2 and 3 is that under Model 3, the outsourced contractor takes full responsibility for O&M, potentially including responsibilities for repairing or replacing some equipment.

The ability to outsource O&M services using Models 2 and 3 is contingent upon being able to procure appropriate contractors. Therefore, at an early stage of developing the O&M strategy, it is appropriate to carry out market soundings to assess the availability and interest of contractors. A number of facilities can be clustered to

FIGURE 4.1 | Options for outsourcing some O&M activities and responsibilities



Source: IFC (2016).

increase the size of the contract to make it more attractive. If there is insufficient interest, it may restrict the options to Model 1, or to Model 2, with limited external support.

In the case of multinational ownership, as for Rusumo Falls, a new entity (such as a special purpose vehicle) may be formed to develop and operate the facility. In this case, the entity would be analogous to a private-sector owner, but with some public-sector constraints. It is important to ensure that this entity has adequate skills, capacity, and resources to undertake construction and operation, which can be determined using the diagnostic process in Step 1.

Related to Model 2 are the training sessions that are typically provided by the suppliers of electrical and mechanical equipment or EPC contractors. This training aims to build capability within the owner's O&M team, and often starts early during the construction contract. Providing that the owner has adequate O&M capability, this training enables Model 1 to be deployed following completion of the facility.

Features and pros and cons of each model are further analyzed in the following sections.

Model 1: Owner retains sole responsibility for O&M

Two versions of Model 1 are considered: Model 1A where the owner is a public entity—typically a vertically integrated public utility, and Model 1B where the owner is an IPP, or a private concessionaire. Although the distinction between the two models is slight, in practice, a public entity is seldom able to make decisions purely on a commercial basis and has greater regulatory constraints and political considerations to take into account. In some countries, a public entity may not be permitted or may be discouraged from contracting out O&M services, and hence may be constrained to using Model 1A in circumstances where Models 2 or 3 might be more appropriate.

Model 1A: Public-sector owner handles all O&M

This is the most common model for power-sector ownership and management in developing countries where O&M functions are embodied within government-owned utilities. Electric utilities in many developing countries are vertically integrated, with responsibility for generation, transmission, distribution, system operation, and electricity sales. This vertical integration can sometimes obscure the costs and efficiencies of each part of the utility, making it difficult to assess whether the assets are being operated efficiently and profitably.

The diagnostic exercise in Step 1 will have determined whether the utility (and its O&M units) is required to increase its resources and capabilities, in terms of quantity and skills of staff, for performing sustainable O&M and whether targeted external interventions are required for improving its delivery of O&M services.

While strengthening or developing its performance under this model, the owner should, in particular:

- ensure that adequate and skilled resources, including leaders and managers, are mobilized
- have strategies in place to manage political influences on the utility and increase transparency in financial management and procurement
- ensure that sufficient financing is channeled to O&M departments, through prioritization within the utility's budget, together with adequate fiduciary delegation at all necessary levels.

Irrespective of the level of success an organization has with hydropower operations, the use of outside consultants to conduct technical and business reviews can still help to improve effectiveness and efficiency, introduce modern approaches to maintenance management, and provide services to assist with the optimization of O&M. Large parastatal utilities looking to improve their fleet O&M performance and enhance the value of their assets can also consider partnering or hiring a similar utility with high-performing hydropower generation to assist in implementing improvements.

Model 1B: Private-sector owner (independent power producer or concessionaire) handles all O&M

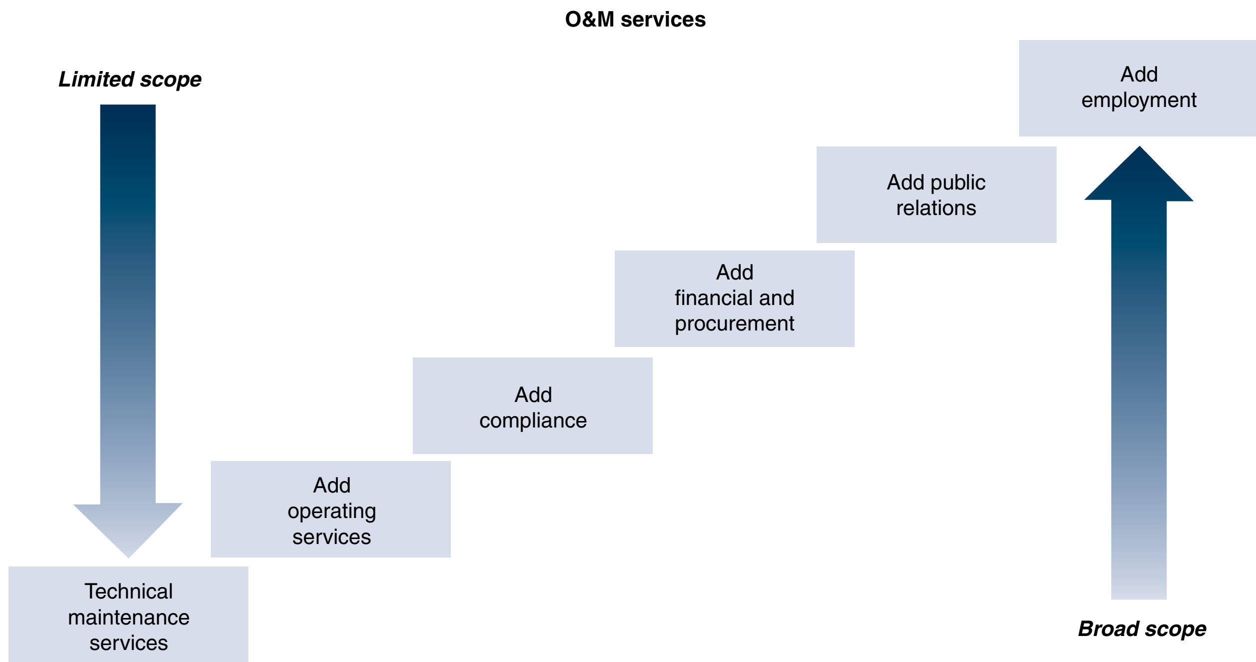
In this case, the private owner mobilizes his internal resources for implementing all O&M activities and may consider recruiting personnel that become staff of the owner's organization. Staffing costs can be highly influenced by whether there is a need to recruit international expatriate staff, or whether appropriate skills and capabilities, augmented by training, are available locally.

For both Models 1A and 1B, owners may consider mobilizing targeted technical assistance that will provide ad-hoc advice and support to the owner in strengthening its capabilities. Technical assistance would then be engaged to provide consulting services for a time-based or lump-sum fee, normally on a short-term basis. In the longer term, it may include embedding experts within the organization to act as advisors to improve operational efficiency through technical and managerial capacity building. In this case, the contractor only assumes the risks inherent in a consultancy contract, although there may also be some incentives, benefit sharing or variable fees and penalties linked to performance indicators. Such contracts represent a limited engagement usually not exceeding a period of two to three years, and generally utilized as a first attempt to build capacity in underperforming enterprises.

Model 2: Some O&M activities are outsourced

Model 2 allows for flexibility in selecting a number of ring-fenced O&M functions to be outsourced in order to augment the capabilities of

FIGURE 4.2 | Scope for outsourcing O&M services in a service contract (Model 2)



the owner. Outsourcing some O&M activities can be limited, extended to some specific areas of maintenance or functional system such as for electromechanical parts and information and communications technology (ICT), or expanded to include a larger number of areas of responsibility. This is illustrated in Figure 4.2, where services are progressively expanded from left to right, until the scope is close to that of Model 3.

Various options for Model 2 are presented in the subsections below.

Technical maintenance services

Technical maintenance services (including maintenance of electrical, mechanical, communication, control, and protection activities) are the most commonly outsourced services. Outsourcing these services allows the utility to resolve equipment problems and carry out the maintenance program on a pre-established schedule at predetermined costs. With a modern plant much of the monitoring can be undertaken remotely, such as from an equipment supplier's head office, enabling cost-effective services to be provided. This level of outsourcing can include hiring engineering firms to carry out maintenance of civil works and inspection and maintenance of hydraulic structures. Contracting such services can also be built around coherent functional systems, which helps in clarifying responsibilities between the owner and service providers.

Plant operation

Responsibility for operation of the plant can also be outsourced. Plant operations can be managed in a variety of ways, depending on the vintage of the plant and the control, protection, and communication links between the facility and control center. Modern data links and communication systems allow remote and centralized operation, theoretically permitting station control and operation to be outsourced. Since local control and operation requires continuous staffing on a three-shift, 24-hour basis, there are potentially large savings to be achieved from outsourcing to a remote operator. However, especially with public-sector owners, these savings must be balanced against the costs of installing modern systems and the likely resistance and socioeconomic consequences of reducing the level of staffing on-site or re-deploying personnel.

Compliance responsibility

The owner also may delegate responsibility to the O&M contractor for compliance with laws and regulations applicable to operations, such as restrictions on reservoir levels, ecological flow requirements, data recording, flow measurement, environmental compliance, workplace safety, health legislation, labor laws, and social responsibilities. Such responsibilities would be considered a reasonable addition, as the operator has control over most compliance actions and is best able to manage this risk as part of the daily operation of plants.

Financial management and procurement

Owners of hydropower facilities can also add responsibility for the management of finances and procurement. The operator could be made responsible for invoicing, collecting fees and revenues, and managing related bank and impress accounts for funding day-to-day operations. Financial responsibility can also be extended to include procurement of services, spare parts, and consumables, according to an approved budget and relevant procurement rules and policies. Such outsourcing can support ring-fencing and improving efficiency and governance of these procurement and fiduciary services.

Public relations

Although most owners retain control over public relations, an outsourced operator can be requested to handle this task when it involves relations with communities who may be affected by day-to-day operations, environmental and social issues, and compliance with site-specific laws and regulations.

Employment of personnel

In a more comprehensive O&M management package, the O&M outsourced contractor could also provide the entire workforce. Doing so may reduce the risks for the owner, but it increases the risk of losing the entire O&M team in the event of a contractual disruption. If the contractor is the employer instead of the manager of the owner's workforce, it has considerable leverage in the event of a dispute. A preferred model is for the local workforce to be on the owner's payroll and seconded to an O&M contractor for the duration of the contract.

Outsourced responsibilities could also be extended to (i) formulate and update O&M procedures and (ii) design and install a maintenance management system (including spare part inventory and ad-hoc management system).

Such a service contract would clearly record the specific operational areas to be transferred to the contractor, but under this Model 2, the contractor's responsibility should not extend to assuming risks related to failures caused by inadequacies in design, manufacturing, installation, testing, commissioning, or normal wear failures of equipment not attributable to poor maintenance or inappropriate operating practices. Contractors would not be willing to take on such risks that are outside of their control. Contractor's remuneration may take different forms but is usually tied to performance with a combination of fixed and variable fees. Penalties may apply for underperformance against agreed targets. Further guidance is provided in section 4.4.

Model 3: All O&M is outsourced

This model places all responsibility for O&M with an O&M contractor.

The poor history of hydropower sustainability in some developing economies has increasingly led to greater reliance on the private sector to deliver new or rehabilitated hydropower facilities and to operate and maintain them under concession arrangements or outright ownership. Fully outsourcing O&M to private sector organizations can, however, be problematic and risky. Doing so within a large vertically integrated public utility may prove to be difficult without first unbundling the sector and introducing adequate regulations for private-sector participation. Despite the challenges, private-sector participation in O&M is on the rise. Successful results have been achieved in emerging economies, especially in Latin America. Having embarked on Model 3, it might nevertheless be difficult for the owner to revert to Model 1 and or Model 2 at a later date.

Among the options available under Model 3 are the following:

Management contract

In this case the contractor assumes responsibility for O&M of the hydropower fleet, normally by placing its own employees in key positions within the organization and providing additional short-term technical, administrative, and training services. The contract will normally be performance based on fixed and variable fees and often has penalties for performance lower than targets. The contractor's risk exposure is restricted to matters within its control and measured against agreed targets. All assets remain the property of the owner, and the contractor is not required to take on any investment risk. This type of contract is often used as an interim measure to improve the performance of an asset, or at the start of operation while a new owner develops his own capabilities. The engagement is usually limited to a period of three to five years depending on the level of managerial competence in the utility and the objectives of the contract.

Affermage (lease agreement)

The contractor in this case takes over operational responsibility, but the assets remain the property of the initial owner. The owner may be paid a lease fee or an affermage fee equivalent to a reasonable rate of return on the assets in order to allow it to reinvest in capital replacements or expansion activities. The contractor is not required to invest and receives its remuneration through improvements in operating efficiency in areas such as billing, metering, collections, fuel efficiency, loss reduction, and productivity. In cases where cash flow improvements are insufficient to pay the contractor due to inadequate cost recovery tariffs, the owner will have to fill the tariff gap and/or defer lease fees. While there are many opportunities to quickly improve operating performance through the introduction of new processes, procedures, and technology, the pace of improvement is tied to the owner's ability to provide capital for investment in the longer term. Performance targets generally relating to service quality standards will also form part of the arrangement. These contracts would normally run for a period of 8 to 15 years.

Lease contracts and *affermage* share similarities but also maintain distinct differences. Both can be used in cases where the owner wishes to engage the private sector by passing on commercial risk and performance incentives without requiring private capital. When procured competitively, both are often tendered on the basis of highest payment to the owner, either in the form of highest lease payment or lowest percentage of revenue retained. The owner remains responsible for investment in assets. In addition to performing O&M, the operator may be expected to oversee the capital investment program. Often these contracts include minimum replacement provisions toward the end of the contract, or requirements that the equipment is handed over in a good operating condition. Both structures assume a greater amount of regulatory and revenue risk, as they are dependent on tariff levels to recover operational costs.

In a lease contract, the operator pays the owner a fixed rental payment (lease fee) for the asset and assumes collection risks but keeps the excess revenue generated. In the case of affermage, the operator retains a portion of revenue generated and then pays the remainder to the owner. Thus, as long as collections cover the fee, the operator's revenue is secured, and the owner takes on a larger portion of the revenue risk. The owner's revenue covers his expenses and profit, and sometimes a portion is ring-fenced or hypothecated for investment in the project.

The next two options would apply only when the owner is a public utility.

Concession

A hydropower concession is a public-private partnership (PPP) arrangement in which the private sector and the public sector share risk. Normally a long-term arrangement of at least 20 years is granted by the government to a special-purpose company in which the government or parastatal utility may or may not be a shareholder. The concessionaire is granted ownership rights and responsibility for implementing, operating, and maintaining the facility for the concession period. The operator is free to operate and maintain the facility to obtain the agreed return on investment within the constraints of the concession agreements, which details legal, employment, environmental, and social obligations.

The concessionaire may also be asked to rehabilitate and refurbish some equipment, which turns the concession into a rehabilitate, operate, and transfer (ROT) model. In this case the concessionaire is conditionally granted asset ownership rights over existing and created assets for the term of the agreement and is responsible for providing, procuring, and managing investment funds. Similar to an affermage arrangement, the concessionaire's remuneration is based on the sale of electricity (as regulated by an associated PPA) and depends on improvements in operating efficiency in various areas such as billing, metering, collections, generation efficiency, loss reduction, and productivity.

Concession agreements usually also transfer some CAPEX responsibility (and/or commitments) to the concessionaire and include requirements on the status of equipment and facilities at the end of the concession period. In cases where cash-flow improvements are insufficient to pay the concessionaire and a reasonable return on investment is impossible due to inadequate cost recovery tariffs, the owner or state will have to fill the tariff gap through subsidization. Normally investments are carried out according to schedules defined in the concession agreement.

In all above contracts, one of the key challenges is to clarify (i) how responsibilities will be divided and how parties will be compensated in case of low performance (especially if equipment fails unexpectedly) and (ii) which parties are responsible for repair/replacement of medium-size and large equipment, the status of which is often not known at the time of signing agreements.[12] This has been the source of major difficulties for SOGEM in managing the O&M contract with ESKOM for the Manantali Dam.

Divestiture

At the extreme end of the outsourcing options, divestiture implies partial or complete sale of the assets to the private sector or to an autonomous electricity cooperative. The legal and regulatory environment should be assessed in order to determine whether the transfer of ownership of state-owned essential services infrastructure assets is permitted.

In the event of divestiture, as with other outsourcing, it is important that appropriate data and documentation are made available to the contractor, in order to ensure continuity in the management and performance of all aspects of the facility. This is particularly important for any documentation relating to safety.

4.2 Strengths and weaknesses of different O&M models

In order to support owners in choosing a model adapted to the local situation, Tables 4.1, 4.2, and 4.3 compare the strengths and weaknesses of Models 1 to 3, respectively.

[12] This is often the case as complete condition assessment of equipment would often require expensive and lengthy dismantling of units.

TABLE 4.1 | Strengths and weaknesses of Model 1

STRENGTHS	WEAKNESSES
1. Responsibility for O&M lies with the entity, which has the greatest interest in ensuring a sustainable flow of revenues and the long-term safety and performance of the facilities. 2. Cheapest arrangement for the owner. 3. Owner retains full control over own investments and operating budget. 4. If utility is not fully qualified to develop a project or conduct O&M, it can acquire ad-hoc and flexible technical assistance to improve O&M functions and to meet new technological challenges. 5. Model requires only expansion and training of existing competent workforce. 6. Labor costs and associated expenses are low.	1. Model subject to government interference, often starving a public owner of finance for efficient O&M. 2. Owner does not benefit from skills, efficiencies, and new processes that could be introduced by outsourcing. 3. Public sector procurement bureaucracy, currency constraints, and payment delays can make it difficult to buy spare parts. 4. Budgets for public owners seldom include provision for future capital investments, leaving plant reliant on donors for financing of life extension, rehabilitation, or refurbishment. 5. Often centralized (and not always transparent) governance of O&M budgets which hampers O&M expenditures (especially for remote plants). 6. Poor incentives for staff to deliver quality O&M.

TABLE 4.2 | Strengths and weaknesses of Model 2 (some O&M is outsourced)

STRENGTHS	WEAKNESSES
1. A way to share and disseminate best practices among owners. 2. Model provides flexibility to the government, the owner, and donors/financiers in augmenting the owner's capability. Alternatively, a package of services can be outsourced to boost the technical and financial turnaround of management of the owner's generation fleet. 3. Reduced responsibilities for the owner: responsibility for certain O&M functional systems transferred to an independent and liable operator via an O&M service contract. 4. Model builds capacity of the owner's organization, allowing gradual transfer of responsibility back to the owner after sufficient periods. 5. Experienced staff can assist with commissioning, eliminating technical issues during the initial operating period. 6. A full or partial service contract can be set up allowing capacity building of the owner's organization with a gradual transfer of responsibility back to the owner after sufficient periods. This option allows experienced staff to assist with commissioning and eliminates technical issues during the initial operating period.	1. Few competent and experienced O&M contractors offer services in developing countries. 2. Model weakens support from government and parastatal utility to make significant changes. 3. Weak procurement and technical capacity can result in weak and poorly defined service contract. 4. Difficulties for outsourced operator to commit to performance without knowing the status of equipment.

4.3 Guidance for selecting O&M model adapted to local context

The selection of the model that best fits an individual facility (or fleet) depends on the business objectives of the facility owner, who is ultimately responsible for the safe and effective performance of the hydropower facilities. It is also strongly influenced by government policy, the regulatory environment, labor laws, and institutional issues that govern the ability to award concessions and/or divest ownership.

The main factors that drive the selection of the O&M model may also include the following:

- type of ownership
- technical, managerial, and financial capacity of the owner
- the availability of local and skilled workforce

TABLE 4.3 Strengths and weaknesses of Model 3 (all O&M is outsourced)

STRENGTHS	WEAKNESSES
1. Operator has incentives to meet or exceed technical and financial KPIs agreed to with the owner. 2. Model is likely to attract concessionary finance and donor interest. 3. Model reduces potential for government interference. 4. Regulation by contract with respect to tariffs and operating agreements. 5. Pre-agreed cost reflective tariff methodology, revenue security, and no rate shocks. 6. Control of all of its own investments and the operating budget. 7. Training of local positions as much as possible to reduce expatriate labor costs and associated expenses. 8. Bonuses and penalties can incentivize operators and concessionaires to perform. 9. May result in quicker and greater improvements. 10. Construction risks often assumed by the concessionaire. 11. Operating and maintenance performance requirements can be jointly established and monitored by concessionaire, financiers, and grantor.	1. Could result in higher overall cost than undertaking similar services in-house. 2. Operators may require risk guarantees (for example to secure offtakes). 3. Often negative public impressions (foreign owned business). 4. Political point of contention (sovereignty over natural resources or fear that private sector will outperform public sector). 5. May trigger organized labor resistance (public sector job loss). 6. The financial sustainability of the project is reliant on the success and bankability of the off-taker and its ability to meet its payment obligations in a timely way. 7. Other future projects or concessions may encroach on the operating boundaries of the facility. 8. Few competent and experienced O&M contractors offer services in developing countries. 9. Model weakens support from government and parastatal utility to make significant changes. 10. Challenging to establish a fair contract due to diverging long-term interests of owner versus short-term revenue maximization by contracted operator. 11. Owner may progressively lose capacity to supervise contractors and concessionaires and to discuss strategic responsibilities and orientations, including CAPEX and investment strategies. 12. Difficulties to distribute financial responsibilities for major repairs, refurbishment, and replacements.

- the enabling environment (regulations, availability of skilled resources, institutional and contractual arrangements, etc.)
- the needs for major repair, refurbishment, or replacement.

1. Type of ownership

Public entities may often want to remain in Model 1, as they are often reluctant to outsource O&M because of lack of support from politicians, unions, and trade and professional organizations. The utility is also often expected to staff such public services in traditional ways in order to provide and sustain local employment. Large parastatals often report to government and are therefore often governed by civil service employment norms, sometimes making it difficult to outsource services. In this case, an independent diagnosis needs to look closely at how best to develop the required skills and knowledge in-house in the short to medium term. Short- to medium-term technical assistance contracts can then be considered. If such support contracts are deemed insufficient or not sustainable, consideration should be given to use of Model 2 or 3 for temporary or longer-term improvements.

Private entities often have fewer constraints on outsourcing some or all responsibilities to other private operators specializing in this field.

2. Owner's experience, capabilities, and knowledge

As assessed in the diagnosis in Step 1, the owner's experience and capabilities will be crucial to the selection of the model and to the definition of levels of supports to be outsourced. It will be easier to apply Model 1 when the owner is experienced with a proven record of efficiency, service delivery, and skilled staff. In cases where new projects are added to an existing fleet, it will also be easier to remain within Model 1 when the owner has proven experience and efficiency. Recruiting necessary staff and reallocating experienced staff to train them should be possible for such owners. However, an inexperienced or inefficient owner may then consider using either Model 2 or 3 (at least as an interim measure) to ensure safe, reliable O&M from the outset. Training of local technical and managerial staff can also be carried out over time, with the vision of increasingly localizing most labor and reducing O&M costs.

Given that hydropower-forced outage rates are usually greatest in the period following commissioning, the O&M strategy will need to ensure that appropriately skilled personnel are available from the start of operation that can make experience-based decisions, resolve technical problems, and continue training local staff until they are able to both manage and carry out all O&M tasks safely. Depending on the owner's comfort level with the O&M management and workforce (in-house or contracted), consideration can be given to strengthening the workforce with an O&M support service contract (Model 2) through the original equipment manufacturer (OEM) during initial operations.

3. Availability of the necessary skills in the national workforce

The level of hydropower development as well as the ability to develop robust curriculums on hydropower are key determinants in the availability of skilled O&M staff on the local labor market. Research will be required to ascertain the quality and quantity of local skills to staff future hydropower development or to make improvements in existing facilities. Regardless of the choice between an in-house or outsourced O&M model, a local workforce has to be involved. The size and quality of the available workforce will then influence the choice of model, including the split of responsibilities between local and expatriate staff.

Countries such as Ethiopia, Ghana, India, Kenya, Mozambique, and Pakistan have developed the necessary education and skills and created local workforces with experience in hydropower O&M that are trained and ready to be hired by an owner, concessionaire, or operator. In Pakistan for example, the New Bong Escape hydropower facility (Case Study 4) was staffed by a private owner through recruiting skilled staff from the large national workforce developed by Pakistan's Water and Power Development Authority. In the first few years of operation, until the owner's internal management team was ready to take over management of the workforce, it contracted O&M management assistance from TNB (Malaysia).

Other countries may face capacity challenges, including lacking a local workforce with hydropower experience, which may result in dependence on regional and international personnel under outsourcing Models 2 and 3. This is particularly the case in post-conflict countries, where whole generations have lost access to education. In these settings, outsourcing (regionally or internationally) for basic skills to implement the O&M strategy over the short to medium term is common. Staffing of the Bumbuna hydropower facility (50 MW) in Sierra Leone, for example, was carried out by bringing in a workforce from Ethiopia Electric Power (EEP). Overall management of the facility was vested in Salini Costruttori, the EPC contractor. Counterpart local staff were put in place for training and shadowing EEP and Salini staff, with the aim of eventually replacing most expatriates.[13]

[13] http://jouleafrica.com/projects/bumbuna-phase-ii

4. Enabling environment and governance

Labor laws and employment requirements: Consideration must be given to the country's labor laws and immigration and employment regulations when selecting an O&M model. A new hydropower owner needs to understand at the planning stage these requirements and restrictions, including laws regarding trade and professional unions, in order to anticipate the barriers to expatriate recruitment, cost implications, and risks involved. Offshore O&M service providers under Models 2 and 3 will have to consider similar market-specific requirements and constraints in delivering services in the targeted country, which may influence their appetite for such services.

The government or utility granting a service contract or a concession (Models 2 and 3) may also include rules and requirements on local hiring in the concession agreement, including for potential transfer of staff to the owner at the end of concession. It is normal for employment terms and conditions for these staff to be transferred during the transition.

Figure 4.3 illustrates how the organizational structure and staffing plan need to be adjusted to take account of the restrictions to labor employment due to national legislation and contractual obligations, that may influence the formulation of the O&M strategy.

Governance: Existing governance systems may also highly influence the selection of a model. If the owner wants to transfer some responsibility to the outsourced operator (Model 2 and 3), it should be supported with associated governance systems and delegation that will allow the operator to implement his duties and vision and deliver efficiently.

5. Needs for major refurbishment or repairs

The needs for major refurbishment or repairs may also influence the selection of model or at least the type of external support to be sought. In the case where major works are foreseen, the owner may wish to include in the refurbishment contracts some O&M services, such as training and O&M support after commissioning.

Selection of O&M strategy

As described above, the main factors determining the choice of O&M strategy are the owner's capacity, the regulatory environment in the country, and the management approach of the institution. Table 4.4 provides strategy options based on the capacity of the owner to execute the implementation and ongoing O&M of a new or rehabilitated facility in a developing country.

These recommendations are illustrated in the decision trees shown in Figures 4.4 and 4.5.

FIGURE 4.3 | Influence of labor laws and employment restrictions on staffing plan

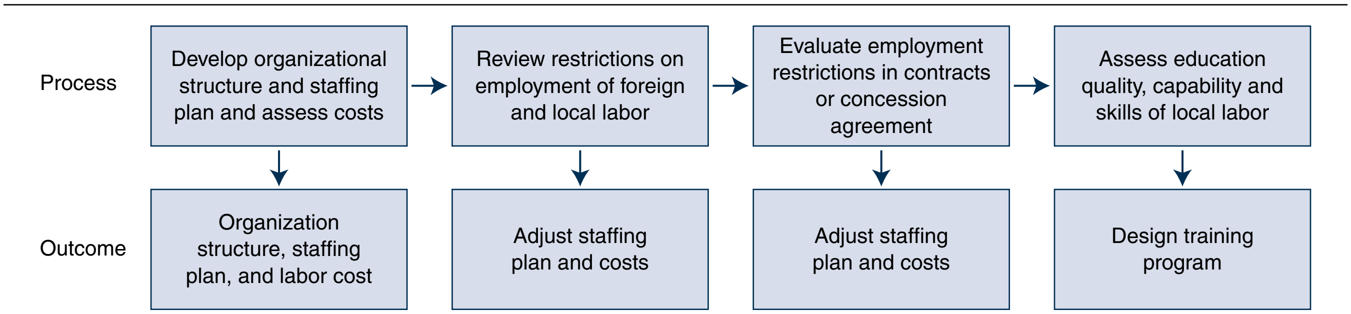


TABLE 4.4 | Strategy selection based on owner capabilities to implement adequate O&M

OWNERSHIP AND CAPABILITIES	POSSIBLE STRATEGY OPTIONS
Public utility with a fleet of poorly managed hydropower facilities	■ Continue operations with internal and external capacity building support if private operators are not allowed (Model 1A) ■ Employ technical advisors/contractors for strengthening weak areas (Model 2) ■ Employ a full-service management contractor (Model 3)
Public utility with a well-functioning and well-managed fleet of hydropower facilities	■ Continue BAU (Model 1A) ■ Seek outside assistance in select areas requiring specialized skills or knowledge (Model 2)
Private entity and first-time concessionaire, or newly created government unit managing a single hydropower facility	■ Build internal capacity and seek support in selected areas (Model 2) ■ Procure a full-service O&M contractor, at least initially, localizing employment over time (Model 3)
Private, experienced concessionaire with a fleet of hydropower facilities	■ Continue BAU (Model 1B) ■ Seek outside assistance in select areas requiring specialized skills or knowledge (Model 2)

FIGURE 4.4 | Public utility decision tree for selection of model

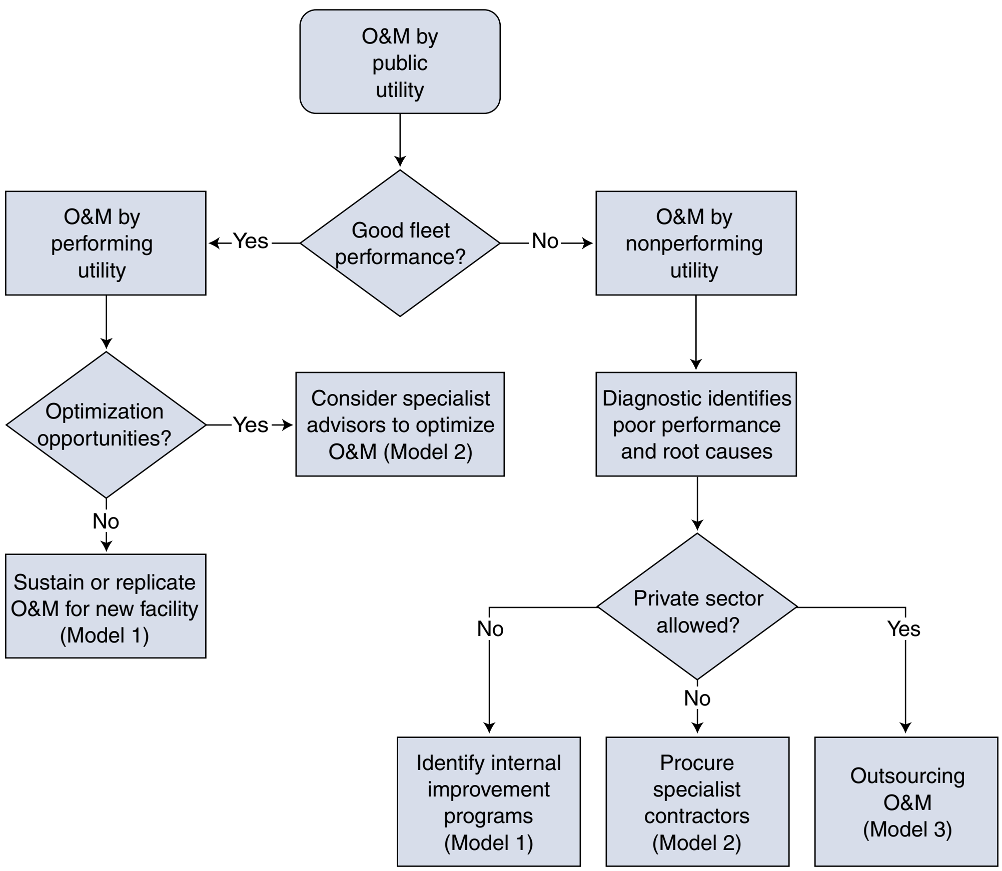
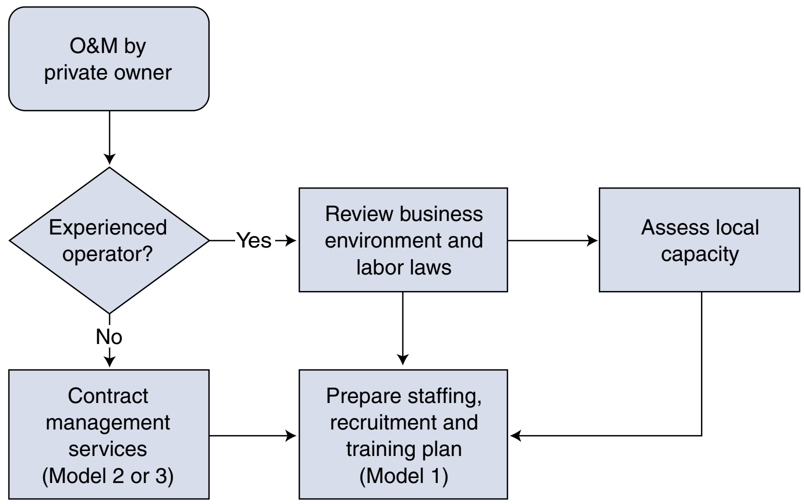


FIGURE 4.5 | Private owner decision tree for selection of model



4.4 Structuring O&M services and management contracts

O&M contracts for hydropower facilities are similar in many respects to other utility management services contracts (MSCs). The terms of reference (TOR), which defines the scope of services, varies depending on the needs of the client. There are not yet any standard contracts for hydropower O&M services. However, examples of O&M contracts for other sectors can be accessed on the World Bank's website.[14]

MSCs are structured in a similar fashion to a consulting services contract. They are usually issued for a fixed duration at a lump-sum price with defined milestones and deliverables and performance incentives. Expenses, including consumables and spare parts, may be reimbursed separately.

Based on the authors' experience and review of (i) hydropower O&M contracts from Canada, Malaysia, Nepal, Pakistan, and Sub-Saharan Africa and (ii) World Bank management services sample prequalification[15] and bidding documents,[16, 17] the following guidance is proposed when considering Model 2 or 3:

Service or management contracts?

The use of management contracts can be a good strategic option when the owner is an:

- inexperienced, first-time concessionaire, or a newly created parastatal unit (managing a single hydropower project implementation)
- existing parastatal utility with a poor performance record of operating and maintaining its fleet of hydropower facilities
- experienced hydropower concessionaire that does not wish to be responsible for recruitment, staff management, and operation of a particular facility.

Service contracts are the preferred option for existing entities (whether private or public) who wish to strengthen their capacity in certain areas or outsource specific activities or responsibilities.

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[14] https://ppp.worldbank.org/public-private-partnership/sector/water-sanitation/management-operation-maintenance
[15] http://documents.worldbank.org/curated/en/297191467998780726/pdf/multi-page.pdf
[16] http://documents.worldbank.org/curated/en/458841468739545677/pdf/multi-page.pdf
[17] Particularly the Technical Note provided for guidance in preparing procurement documents, prequalifying bidders, and tendering the services. The Technical Note provides systematic advice not only on the preparation of documents and the management of the procurement process, but also provides examples of utility MSC service contracts from developing countries and describes the pros and cons of different options when formulating the key components of an MSC for a utility.

Scope of services

The scope of services will depend on which services are to be outsourced and which responsibilities are to be transferred. The scope can range from managing only technical maintenance functions to managing facility operations, financial and administrative affairs, and external relations. The contract should spell out the scope of services in the following areas:

- operations
- maintenance (including distribution of responsibilities for expenditures)
- environmental, social, and license compliance
- regulatory and legal compliances, including interaction with PPAs
- responsibilities in terms of OPEX and CAPEX expenditures
- procurement and financial management
- public interaction and relations with communities
- human resources and payroll.

Request for proposals and draft contracts should then ensure that outsourced services are well defined and that the demarcation between responsibilities and liabilities is clear. The contract should also embody the following features:

- fair balance between both parties in terms of risk allocation
- fair balance between risks and rewards to the contractor
- variable fees that are sufficient to incentivize the contractor (at a minimum, fixed fees should cover the contractor's direct and indirect costs, which leaves normal profit levels and beyond, as variable)
- preferring bonuses to penalties for meeting targets, hence promoting positive incentives (as bidders may otherwise include the risk of penalties in the bid price, thereby losing the incentive while resulting in a higher cost)
- subsidiarity: risks should be shared based on who is best able to manage and bear them
- detailed description of responsibilities for repairing and/or replacing equipment (especially expensive ones or those which may result in lengthy outages or large generation losses).

A public utility may base the contract requirements on the demarcation of responsibilities and liabilities that makes them more comfortable and limits outsourcing, assuming that the situation will improve in the future. However, governments and donors may sometimes look for deeper involvement of the third party, assuming that a private contractor will assume greater responsibility and accountability for achieving specific targeted outcomes. Such aspects should be addressed carefully through constructive dialogue and based on the assessment of capabilities carried out in Step 1.

KPIs

Improvements in KPIs can be used to trigger incentive payments. Areas that can be monitored for determining success and the payment of variable fees include the following:

- energy production and revenues (actual versus planned, taking into account long-term hydrology)
- generation capacity availability (actual versus agreed targets)
- forced outage rates and durations (actual versus agreed targets)
- capital and operating budget performance (actual versus planned/committed)
- workplace safety indicators such as accident frequency and severity indices (actual versus agreed targets)
- environmental and legal compliance incidents (number and severity)
- maintenance activities (actual versus planned)

- store inventory value (actual versus planned)
- training program performance (actual versus planned).

Table 4.5 has been extracted from an existing management contract and provides illustrative figures and thresholds on some of these KPIs.

Bonuses, penalties, and incentives

As discussed above, bonuses are preferred to penalties or liquidated damages to encourage good performance.

When relevant, penalties and liquidated damages need to be commensurate with the contractor's revenue. In virtually all cases for hydropower, the O&M contractor's revenue is a small portion of the facility's income. Hence, even setting the level of penalties or liquidated damages at the full annual value of the contract will not safeguard the owner from lost revenue during prolonged outages resulting from poor operation.

Conversely, bonuses which provide a share of the improvement in the facility's income can substantially increase the contractor's revenue and provide a good performance incentive. The best protection for the owner against revenue loss is therefore the selection of a highly competent and experienced O&M contractor, appropriate insurance cover, and a contract structure that encourages and rewards good O&M practice. Bonuses typically range from 10–35 percent of the annual base management fee paid to the contractor.

O&M contracts should also include the possibility of terminating the service as the ultimate penalty for default of the contractor/concessionaire, with an adequate period of handing over, which in turn is compensated according to its progress and success.

Procurement

While there is plenty of international capacity and capability to provide support services under Models 1 and 2, there are few experienced operators able or prepared to take on Model 3 O&M contracts, especially in developing countries. In setting up procurement processes, it is particularly important to ensure that quality and experience are the main factors for adjudication. If price is perceived as the primary criterion for selection, good quality O&M contractors will not participate in the process, and only contractors with poor capability and experience will tender (with often underestimated and insufficient resources in their proposal). The performance of the outsourced O&M may be little better, if not worse, than if the O&M function had been retained in-house.

TABLE 4.5 | Example of performance measures used to calculate incentive payments

INDICATOR	TARGET VALUE	CALCULATION METHOD	WEIGHT IN PENALTIES/BONUSES (% OF TOTAL)
Overall availability factor	97%	AF = (available hours/reporting period hours) × 100	20%
Transmission availability factor	98%	AF = (available hours/reporting period hours) × 100	20%
Overall generation-forced outage rate	1%	FOR = (FO hours/FO hours + service hours) × 100	10%
Transmission-forced outage rate	1%	FOR = (FO hours/FO hours + service hours) × 100	10%
Budget performance variance	≤+5%	Annually not more than 5 percent above approved budget	10%
Increase in store inventory value	≤+5%	Annual increase of not more than 5 percent	5%
Accident frequency (per 100,000 hours worked)	1	1 lost-time injury per 100,000 hours worked	15%
Accident severity (per 100,000 hours worked)	10	10 lost-time days per 100,000 hours worked	10%

Monitoring

O&M contracts should be monitored and administered by competent individuals or organizations, either from within the owner's team or from external companies. This monitoring will aim to ensure compliance with the contract terms, confirm that performance parameters are met, receive documents and deliverables on the owner's behalf, agree to contract variations, certify payment, and assist with settlement of disputes.

Regular reporting of O&M performance by the monitor will provide the owner with data to evaluate the success of the O&M strategy, which can then be adjusted and improved if necessary.

Transfer condition

The O&M contract will typically include clauses relating to the condition of the facility when it is handed back to the owner at the end of the contract term, or on termination. It will include details of tests and inspections that will be carried out, and the process for valuing defects to establish penalties or payment deductions. It should also include details of dispute resolution procedures in the event that agreement on condition and valuation cannot be reached by the parties.

4.5 Insurance

Insurance is a valuable tool for managing and mitigating risk in hydropower. A diverse range of insurance products are available covering all stages of hydropower development and operation. Some insurances, such as third-party liability and vehicle insurance, are required by law or are specified in concession agreements and operating licenses. Other insurances are optional and will be taken out in order to mitigate costs or revenue loss. Advance loss-of-profit insurance may be placed during construction in order to protect the owner's revenue stream in the event of a delay due to an insurable event. Business interruption insurance (BII) is often taken out during operation to supplement the owner's all-risk policy. The latter will cover the cost of restitution of the damaged elements, while the former protects the owner's revenue stream.

When a detailed risk analysis of potential failure events is undertaken, as discussed in Step 1, insurance proceeds are considered to mitigate the impacts when determining the residual risk.

Insurance may also be available to cover failure by off-takers to comply with their payment obligations under the PPA.

Service and management contracts may include insurance requirements in order to cover the main risks to the assets or that may result in revenue loss. Public utilities often self-insure for revenue loss and reconstruction costs, while commercial insurance is generally mandatory for private-sector owners and operators. Self-insurance can lead to prolonged reconstruction periods if funds are not readily available, and hence should be discouraged.

Insurance is necessary before project completion and during plant operation. Insurance during the pre-completion phase covers construction, environmental, and political risks, including reconstruction costs and advanced loss of profit. Insurance during the post-completion phase covers operational failures, and environmental, political, nonpayment, and transfer risks. During the operation phase, insurance usually covers all risks associated with plant and equipment, breakdown cover, loss of revenue (business interruption cover), and public liability.

Insurance costs are budgeted under the annual OPEX budget. They typically account for roughly 0.5 percent of the construction CAPEX. Insurance companies typically require hydropower owners and operators to maintain the facility in accordance with the manufacturer's recommendations and good industry practice. This includes carrying out preventive, planned-interval maintenance in accordance with the O&M plan.

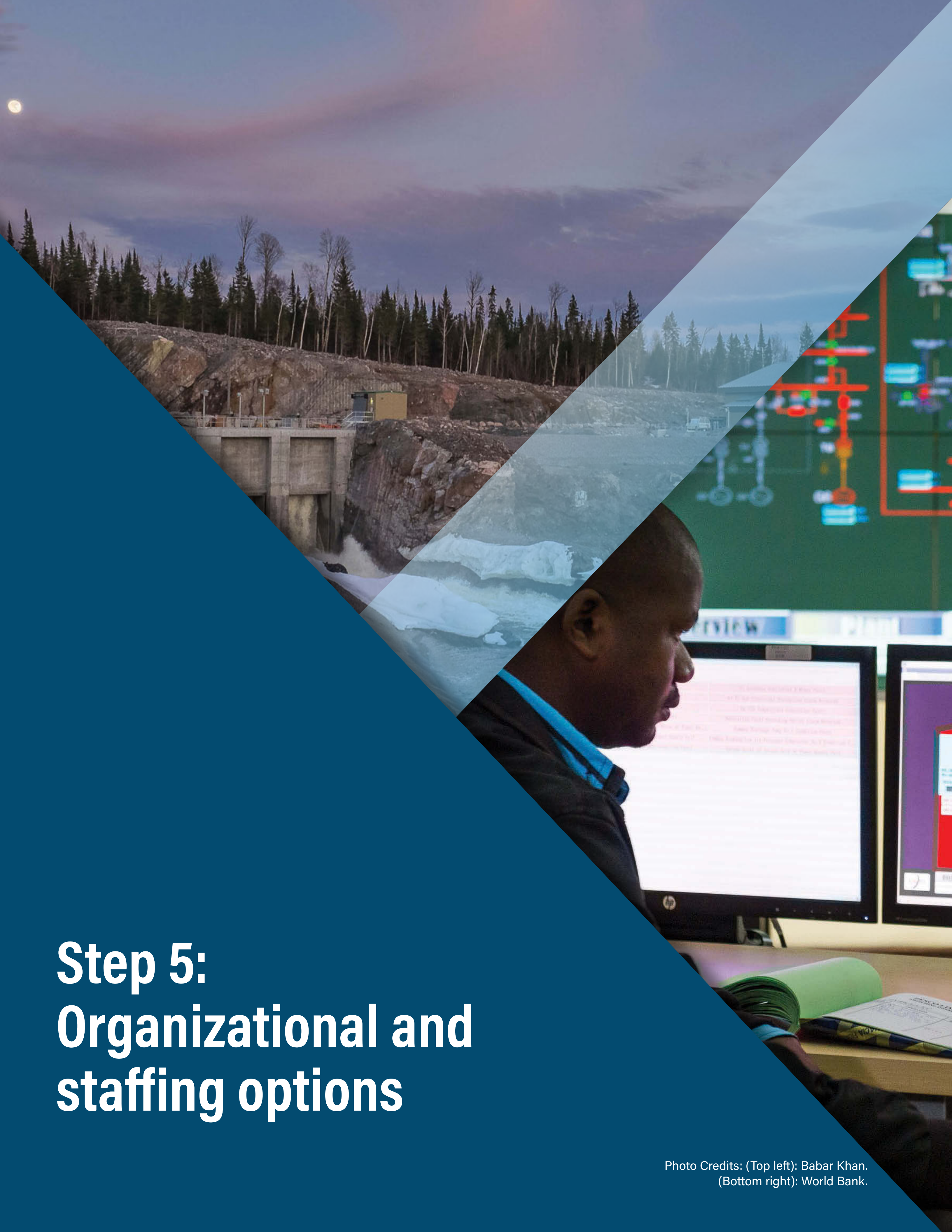
Increasingly, insurers prefer that operators transition to condition-based maintenance, using CMMS. They provide discounts for keeping critical spare parts in inventory. Insurance companies generally audit the O&M annually to ensure compliance with the policy. Among the benefits of developing a good O&M strategy and applying good industry practice to O&M is a potential reduction in insurance premiums.

It is important for developers of new projects and owners of existing facilities to consult with insurance advisors and brokers at an early stage, as aspects of the design will affect the cover available and the premium. This can have fundamental impacts on the configuration of a Greenfield scheme, or the design of a refurbishment project.

Insurance typically covers the owner, the operator, and other named parties on the policy, including those with a commercial interest, such as lenders.

THE OUTPUT FROM STEP 4

Is the selection of the model to be used for the O&M strategy. This will be a choice from Models 1, 2, or 3, along with their options and variants. A list of contracts/operators envisaged to be mobilized will also be provided, including description of key responsibilities and strategic terms of the proposed contracts (time-based, lump-sum, performance based, bonuses/penalties, etc.).



Step 5: Organizational and staffing options

Photo Credits: (Top left): Babar Khan.
(Bottom right): World Bank.

Having selected and structured the O&M model in Step 4, the required organizational structure is developed in Step 5, giving consideration to staffing levels, and the training and experience required.

A sustainable O&M strategy aims to ensure that qualified technical and managerial resources are in place to deliver O&M services effectively and safely within a framework of responsible business practices. By doing so, it also seeks to strengthen human resources and ultimately improve institutional capacity and corporate governance, as well as the business environment.

The owner can develop a recruitment, staffing, and training plan suited to the O&M model chosen in Step 4. For a new facility, recruitment, staffing, and training takes into consideration the country-level business environment and the capability of the country's workforce to perform hydropower O&M. For an existing fleet seeking to improve its performance, the owner aims to prepare a plan making the best use of in-house resources combined with external advisors or contractors in accordance with the chosen O&M model.

For all models, whether O&M is outsourced or undertaken internally, it will normally be appropriate to build the capacity and skills of local personnel. This helps to ensure the sustainability of the organization through reducing reliance on foreign staff and will generally reduce the cost of labor.

5.1 Organizational structure

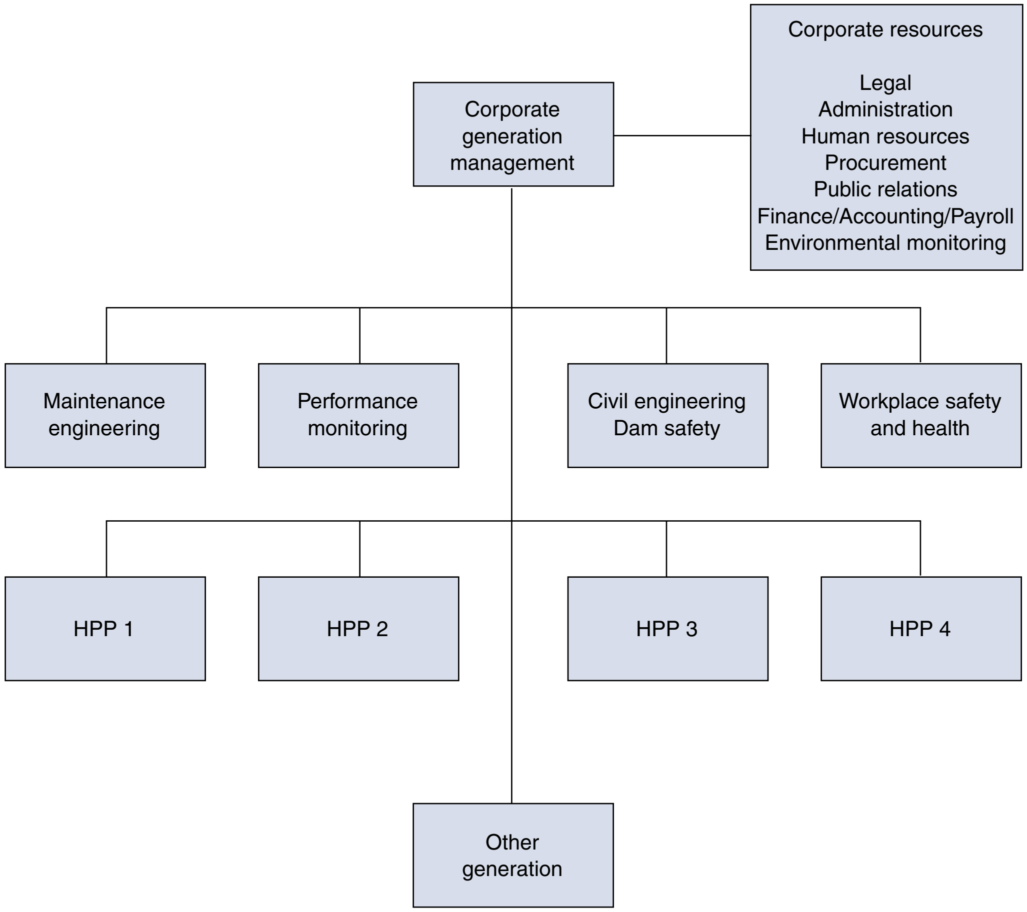
The organizational structure of O&M activities varies significantly depending on (i) whether the owner is responsible for O&M of one or several sites and (ii) the type of facility.

Multi-site arrangements and corporate support

The success of sustainable hydropower O&M for a company with a fleet of facilities depends largely on how well the organization functions in meeting its corporate objectives. The success of the organization depends on the quality of its employees (skills, knowledge, and experience) at all levels of the company and how well the human resources are selected, trained, and managed. The differences between the performance of well-run and poorly performing utility fleets are evident at multiple levels. The greatest responsibility rests at the senior and management levels. Shortcomings should be identified during the diagnosis in Step 1 and through a more detailed operational audit.

The organizational structure is specific to an individual owner and facility/fleet. It will vary with the size and number of facilities in the fleet as well as the distance between sites and distance between communities served. Ken Gen—the publicly traded owner of most of Kenya's power generation—has, for example, adopted a typical O&M organizational structure for public sector multi-facility managers, illustrated in Figure 5.1. This structure can also be used for managing the

FIGURE 5.1 | Centralized management and support services for a fleet of generation facilities



O&M functions of multiple plants located near one another, such as facilities in a cascade on a river system. The organization chart demonstrates centralization of many corporate functions that support hydropower O&M activities, such as human resource administration, finance, procurement, legal, regulatory, ICT, security, and transportation.

As well as the central administrative function, support services that are usually provided at the corporate level to all facilities in a fleet include the following:

1. **Maintenance engineering:** This corporate function assists site and fleet personnel with the design and monitoring of maintenance programs and provides engineering services to solve O&M problems. In some organizations, this group may also be assigned responsibility for the planning, justification, and execution of major maintenance and capital projects.
2. **Performance monitoring:** This corporate function is responsible for monitoring the performance of various utility measures, including hydropower performance. Performance monitoring requires hydrological expertise to ensure that water resources for all hydropower facilities are managed in the most efficient manner possible.
3. **Dam safety and civil engineering:** This function is generally separate from other support services. It is responsible for dam safety programs and formal monitoring and inspection of all civil structures, with a focus on water containment structures. This group works closely with civil maintenance staff at each site.

4. **Workplace safety and health:** This group is responsible for supporting site safety programs and accident investigation in a consistent manner across the company.

Each site will have its own staffing structure for delivery of local O&M services, and the size and strength of this team depends on how much of the services are devolved to the site. For some modern facilities, such as SSE's plc fleet in Scotland, the entire O&M service is centralized, and no personnel are specifically allocated to a facility.

In the case of individual projects that do not form part of a fleet, including many IPPs, the entire corporate structure must be developed for the project. However, the corporate and administrative functions are often separated from the generating facility, especially if the hydropower site is at a remote location.

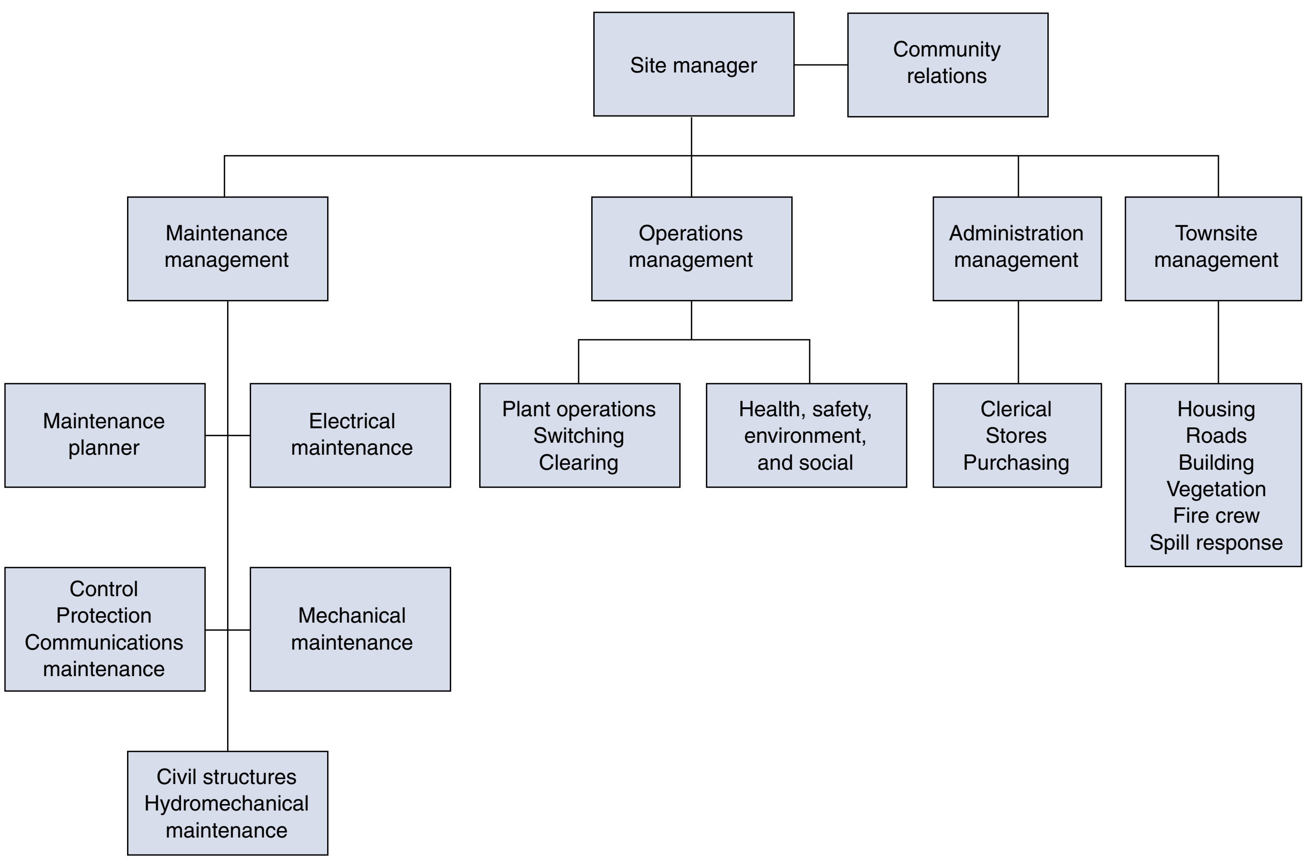
Local O&M structure

As illustrated in Figure 5.2, functions that need to be staffed on-site O&M include the following:

1. electrical maintenance
2. mechanical maintenance
3. control, protection, and communications maintenance
4. civil-works inspection and maintenance
5. planning, analysis, and scheduling maintenance
6. switching and clearing
7. administration and purchasing/inventory
8. town-site O&M and administration (if applicable).

Depending on the country and location of the facilities, staffing may or may not involve

FIGURE 5.2 | Organizational structure of typical hydropower site



residency at the facility. The company may in some instances provide housing for the O&M team, except for casual local labor. The more remote an installation is, the more difficult it is to staff and the more expensive it is to operate and maintain.

The organization chart in Figure 5.2 is representative of a single facility contained within a larger fleet in a vertically integrated utility—the norm for most developing countries with state-owned monopolies and centralized-support functions shown in Figure 5.1. This organizational structure usually entrusts day-to-day site O&M responsibility to facility personnel, who are guided and constrained by corporate policies, operating procedures, and rules, and by technical and administrative parameters.

The arrangements for organization and staffing for a single plant site depend on six main factors:

1. ***Experience of owner and/or its service providers.*** An experienced owner or one with an experienced service provider staffs the facility in accordance with the characteristics of the facility and the principles of safe practice.
2. ***Size of the plant.*** The size of the plant determines the cost-benefit impacts of having staff available on-site to deal with forced or unplanned outages. For smaller facilities, the value of lost generation caused by longer response times may not warrant having all disciplines reside at the facility. For larger installations, the costs of having specialists on-site (or regionally located to serve several facilities) may be justified. In the case of a private concession, PPA, operating-agreement, or concession-agreement, conditions may need to be considered with regard to staffing, longer response times, and agreed upon availability metrics.
3. ***Age of plant and installed technologies*** *(remote control, monitoring and data acquisition, real-time condition monitoring, modern human-machine interfaces).* Depending on decisions made at the time the specifications for the plant design or design of upgrades for rehabilitation are finalized, the plant may be modified for remote operation and monitoring. Local plant operators may not be required if technicians carry out switching and clearing procedures when on-site for maintenance purposes. Condition monitoring is also helpful in putting in place efficient maintenance programs with enhanced predictive capabilities.
4. ***Access*** *(remoteness).* The remoteness of the site affects the owner's ability to attract and retain competent staff, particularly younger staff with families, who require access to good education, health care facilities, and recreation services. Another consideration is the increased response times if staff required to respond to an emergency or resolve an unplanned outage are not present at site. Access may be hampered by customs policies that may not allow for visas on arrival or multiple entry visas, preventing real-time international assistance from the owner, an engineering consultant, or a representative of the original equipment manufacturer.
5. ***Division of responsibilities between central/corporate and site teams.*** Centralized office functions may include public relations, contract management (PPA, concession agreement, and operating agreement), and financial matters, including energy billing and banking, human resource management, purchasing, and environmental, regulatory, and legal compliance.
6. ***Outsourced functions.*** These will depend on the model and external supports mobilized.

Regardless of the ownership structure, it is desirable for all stakeholders (including contractors and service providers) to localize as many jobs as possible without introducing unacceptable risks. Before making any assumptions about local capacity, it is advisable to gain a good understanding (through the diagnosis in Step 1) of the quality of education and training in the country and the depth and availability of hydropower O&M experience. Poor planning can lead to significantly underestimating O&M costs and to risks that are usually avoidable.

Classic job titles, profiles, and associated tasks and requirements are provided in Appendixes D and E. The owner may use these tables as checklists that could provide guidance or feed job descriptions for recruiting key positions that are not yet staffed. They can also use them to update job descriptions for staff already employed.

5.2 Staffing levels

The number of staff required to operate a hydropower facility is largely dependent on the size and number of facilities and degree of automation, and is also affected by the nature and location of the facility and the owner's approach to staffing. Each facility and location are individual, and staffing requirements vary widely as illustrated by the case studies.

In addition to the six main factors previously described, the following factors are also among those driving staffing requirements:

- **National capabilities:** lack of local capability means expensive expatriates are required.
- **Corporate capabilities:** owner/operator may not have skills and systems for efficient working.
- **Labor costs:** low labor costs tend to encourage high staffing levels rather than efficient operation.
- **Politics:** governments often overstaff facilities to boost employment levels.

As an example of extremely low staffing, the fully automated and remotely controlled 100 MW Glendoe HEP in Scotland, owned and operated by SSE, does not have any full-time employees on-site. The facility is inspected by a roving team of technicians who also cover other hydro facilities in the vicinity. Monitoring and operation is carried out from a centralized control facility, where 80 stations with 125 generating units are operated by fewer than 20 staff, who provide continuous round-the-clock coverage. Hence the O&M at Glendoe is covered by the equivalent of a handful of staff.

This contrasts with 1,330 MW Kainji and Jebba HEP in Nigeria, which, prior to privatization, employed 450 managers and staff for O&M. Following privatization, this number was reduced to 159 staff.

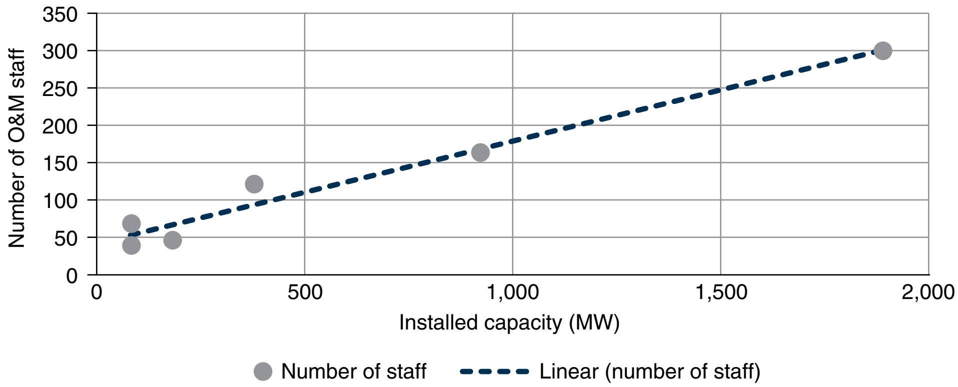
An indication of staffing levels and structures for well-run hydropower facilities is provided in the case studies summarized in Table 5.1 and in the final chapter of this report. More detailed descriptions of the case studies can be found in the companion report titled *Operation and Maintenance Strategies for Hydropower—Six Case Studies*.

TABLE 5.1 | Staffing levels at case study schemes

NAME	COUNTRY	CAPACITY (MW)	NO. OF PLANTS	NO. OF STAFF
Statkraft Portfolio	Brazil	188 MW	6	45
Mount Coffee	Liberia	88 MW	1	36 *(18 national + 18 international)*
Kainji and Jebba	Nigeria	922 MW	2	159
New Bong HEP	Pakistan	84 MW	1	69
Nalubaale and Kiira	Uganda	380 MW	2	120
Salto Grande	Uruguay/Argentina	1,890 MW	1	>300

Source: IHA (2019).

FIGURE 5.3 | Number of staff compared with installed capacity for case studies



It can be seen from these examples that there is a wide range of staffing levels, even for efficiently run facilities. Plotting the number of staff against installed capacity (Figure 5.3) based on these case studies suggests a tentative correlation between the size of a facility (or fleet) and the number of staff required to operate it.

However, the plot in Figure 5.3 should be used with caution, since it is only based on six case studies and since the number of staff required is driven by many other factors as previously discussed. It can tentatively be used as a guide to the requirements for an efficiently operated facility where most services are provided on-site, and the plant is operated locally without support from a centralized team.

5.3 Education and training

Training requirements

To be sustainable, an O&M strategy requires the continuous development of human resources to competently carry out O&M functions for the duration of operations. High-quality, secondary education and technical colleges are needed to produce competent technicians, and accredited universities are needed to provide the bachelor-level education required for professional positions.

Organizations such as the National Power Training Institute of the Indian Ministry of Power, or the Kafue Gorge Regional Training Centre in Zambia offer training in O&M of hydropower facilities.

Appendixes D and E provide recommendations for the education and skills required to be considered for key O&M positions. Table 5.2 gives an illustration of these requirements for an electrical engineer and a technician.

In developing countries, it is common practice to consider technicians or engineers to be qualified upon completion of the academic portion of their training (diploma or degree). In most countries, there are no formal practical training requirements after graduation. Formulation of the staffing plan requires (i) close examination of the quality of education in the country, (ii) appropriate adjustments to ensure that adequate time and operating funds are allocated to education and training, and (iii) that additional costs of importing talent during training periods are included in the budget.

Hydropower-specific training

For new hydropower developments, training should be planned before construction starts and implementation should begin during the construction phase, at least one or two years before commissioning starts. A common model used when adding a new plant to a fleet is to select staff with the right credentials within the existing organization and to ensure that they participate in training programs run by the

TABLE 5.2 | Training requirements for technician and engineer at typical utility in North America

POSITION	SECONDARY EDUCATION	POST-SECONDARY EDUCATION	ON-THE-JOB TRAINING	ADDITIONAL SITE-SPECIFIC ON-THE-JOB TRAINING	QUALIFICATION
Electrical or mechanical engineer	Grade 12 matriculation with acceptable standing in math, physics, and English	University B. Sc. in electrical or mechanical engineering, 4 years	Engineer-in-training, 3 years		Receives professional engineer status after 7 years
Electrical or mechanical technician	Grade 12 matriculation with acceptable standing in math, physics, and English	Technical college diploma in electrical and mechanical technology, 2 years	Electrical or mechanical technician training program practical and academic, 4 years	Receives restricted status as technician-in-training, 1 year	Qualified technician status after 7 years

original equipment manufacturer (OEM) and are involved in the installation and commissioning of the plant that they will eventually operate and maintain. In addition, local engineers should be taken on by the owner or the project implementation unit for training throughout both the project design and construction phase. This type of training generally works well for a well-functioning utility with staff possessing the required skill sets to make full use of the practical training. It is more challenging for a poorly functioning utility.

When preparing human resource plans (including plans for staffing and training), the owner should take the following factors into consideration:

- the availability of educational opportunities
- the quality of secondary and post-secondary education of available staff
- the quality of the country's educational institutions
- the authenticity of educational documentation
- the existence of other hydropower facilities in the country and their O&M performance
- the experience of recruits and the relevance of this experience to the tasks associated with hydropower O&M
- the experience of the facility owner and/or service providers.

Partnering with universities, other utilities (Box 1), and specialized training institutes can also be part of the strategy for finding and training staff. International platforms, such as the one provided by the International Center for Hydropower (ICH), can also build and strengthen capacity.[18]

BOX 1 | Example of partnership between utilities

For a year before commissioning, staff of the 76 MW Muela hydropower plant in Lesotho were given hands-on training in Ireland at an ESBI hydropower plant. After commissioning and manufacturers' training, they were supported by an operations management specialist from Manitoba Hydro International for another five years of operations.

THE OUTPUT FROM STEP 5

Is the organization and staffing structure (including job titles and organograms) required for implementation of the O&M strategy. The staff numbers, grades, qualifications, and status (expatriate or local) are used in Step 6 for preparation of O&M budgets.

[18] http://www.ich.no/detalj/courses/3579

Step 6: Estimating financial costs

Photo Credits: (Top left): Pierre Lorillou.
(Bottom right): Babar Khan.

The process for estimating O&M costs is defined in Step 6. For existing hydropower facilities, this cost estimate provides a basis for allocating a sufficient budget to ensure that facilities can be operated in accordance with good industry practice. For new projects, the estimates also provide input to the economic and financial analysis undertaken to determine the viability of the project.

6.1 Factors affecting O&M costs

O&M costs for hydroelectric facilities are usually treated in two categories:

- **Operating expenditure (OPEX),** which covers all day-to-day operating costs associated with normal administration, operation, and maintenance of the facility, and its associated infrastructure.
- **Capital expenditure (CAPEX),** covering one-off activities such as major refurbishment, overhaul, upgrades, and replacements.

For the purposes of validating the O&M strategy, the costs are often estimated in USD. However local or other international currencies may also be used, matching the currency that was adopted for estimating the benefits in Step 2.

The costs of hydropower facility O&M vary considerably due to a range of factors including:

- **Nature of the facilities:** complex facilities with multiple units, extensive civil works, and extensive associated infrastructure cost more to operate than simple compact facilities.
- **Age:** older hydropower facilities with manual controls, analogue systems, and outdated equipment cost more to operate than modern, fully automated, remotely operated digitalized plants.
- **Condition:** facilities in poor condition requiring continuous attention and suffering frequent failures cost more to operate than facilities in good condition. Facilities in poor condition are likely to require significant capital investment programs.
- **Location:** facilities in remote locations, especially where accommodation, utilities, and other facilities need to be provided for O&M staff, cost more than hydropower facilities in urban locations.
- **Country:** since staff costs form a significant portion of OPEX, the labor costs and available skill levels in the country have a significant impact on O&M costs, especially if lack of skills means that expatriates are required. Some other input costs (vehicles, fuel, etc.) also vary by country.
- **Regulatory regime:** the cost of permits, licenses, registrations, rents, and other administrative outgoings varies from facility to facility and by country.
- **Owner's approach to staffing:** many traditional public utilities carry larger staff resources than commercial organizations with leaner operations.

6.2 Estimating OPEX budgets

OPEX budgets are usually prepared to estimate the cost of operation per annum. As costs reflect day-to-day operations, which are continuous throughout the lifetime of the facility, these costs are usually treated as a constant value throughout the lifetime of the plant, although usually there are allowances for inflation.

Few O&M cost components are dependent on the run-time or energy output of the hydropower facility. Apart from spare parts and lubricants, O&M cost components are mainly fixed costs. Thus, for the purposes of this assessment, there is no need to separate the OPEX into fixed (per annum basis) and variable (per MWh basis) components.

For an existing fleet, the historic costs of O&M can provide a good basis for this cost estimate adding, where appropriate, components introduced in the new O&M strategy.

The primary components of an OPEX budget can be classified as follows:

Head office, administration and engineering costs

Head office costs include all administrative costs of running the business, such as management and support staff, office premises and equipment, licenses, permits and other regulatory costs, rents, property taxes, utility bills, accounting, auditing and legal fees, including costs of administering contracts and other costs associated with selling electricity. Provisions should also be included for advisory services, although fees for studies and designs associated with major projects are typically included in the CAPEX budget. Recruitment and training costs for head-office staff should also be included. The components of staff costs are described in more detail below.

Public utilities and fleet operators are able to spread the head-office costs across their fleet of assets, whereas single station owners must attribute all these costs to a single hydropower facility.

Power station and control room staff

All staff involved in the day-to-day operation of the facility, including the control room, substations, transmission interconnector, and all associated infrastructure (other than staff accommodation camps) are included in this cost component. The cost of staff should include direct salary costs, bonus and incentive payments, overheads, social charges, and any allowances. The costs of transport to and from the site should be included, together with other costs associated with expatriate and remote location packages. The cost of recruitment, training, leave, and other indirect costs should be added.

In preparing the budget, it is common to identify the staff positions for key staff and management and estimate their salary costs based on the required experience and qualifications. The job titles, descriptions, and requirements in Appendix C will help with this exercise.

Staff numbers should include office support and administrative staff, drivers, security guards, cleaners, and laborers. Vehicle maintenance technicians, stores clerks, and medical staff (at the power station, but not the camp clinic) are included in this category.

The cost of O&M staff forms a very significant portion of the OPEX budget. While the cost varies from facility to facility, it may comprise up to 50 percent of the total OPEX cost.

Planned maintenance and inspection costs

Depending on corporate accounting policy, planned maintenance works may be included in either the OPEX or the CAPEX budget.

Planned maintenance and inspection may include, but are not limited to:

- powerhouse generating equipment repairs (civil, electrical, mechanical)
- grid interconnection repairs
- dam repairs (civil, electrical, mechanical)
- access roads/bridge repairs
- powerhouse building repairs
- scheduled inspections (civil, electrical, and mechanical)
- other miscellaneous items depending on production and run-time, such as consumables, oil, lubricants, and spare parts.

The planned maintenance and inspection costs will vary from year to year and may have a cyclical pattern. Thus, a five-year or long-term budget should help to cover this cyclical pattern. For budgeting of a new facility, an average cost over the life of the facility may be sufficient as it will cover the variability of these costs on an annual basis.

Equipment and vehicle costs

O&M equipment costs to be covered in the OPEX budget include:

- major maintenance and testing equipment
- hand tools
- office equipment (computers, printers, telecoms, portable devices, furniture, etc.)
- personal safety equipment, including radios, satellite phones, and venting equipment
- workshop equipment (compressors, welding sets, etc.).

The cost of this equipment needs to include provision for consumables and any service fees (such as for mobile or satellite phones).

The cost of operating and maintaining vehicles used for O&M should also be budgeted. O&M vehicles usually include vehicles for personal transport (typically 4WD utility vehicles), buses, trucks, tractors, trailers, bowsers, and mobile cranes. The OPEX cost for these vehicles will include either the rental cost or the amortization of the purchase cost, maintenance, fuel, licenses, and insurance, etc.

Insurance

Insurance costs vary depending on the value insured, the nature of the facility, the location, the quality and strategy of O&M, and the insurance products purchased (section 4.5).

Utilities

The cost of utilities includes the costs of water, sewerage, and telecoms services provided by external organizations. It may also include the cost of electricity purchased from the grid when the facilities are not generating, or at locations supplied from the grid rather than tapped off before the export meter.

Environmental and social costs

Any costs for environmental or social obligations, such as monitoring, catchment management, livelihood restoration, or maintenance of resettlement villages, need to be included in the budget. These costs are specific to individual facilities, and require a bespoke estimate based on the results of the environmental and social impact assessment (ESIA) and other studies.

O&M camp

The costs associated with provision of accommodation can vary from zero, in the case where there is adequate accommodation nearby, to a very substantial cost in remote locations. In addition to the cost of houses, costs may include the provision of water, drainage and sewerage, security, education, medical and leisure facilities, and other facilities and services needed to run a small village.

As with the power station, the costs need to include provision for staff, vehicles, equipment, and consumables.

Contingencies

It is normal to include a contingency in the OPEX budget estimate. The level of contingency depends on the stage at which the estimate is made: during feasibility studies a contingency of 10 percent to 20 percent is common, while during operation, once the costs are more certain, 5 percent to 10 percent may be adequate. However, care is needed to avoid double accounting. If a conservative approach is adopted in compiling the budget estimate, a large contingency should not be included as well.

OPEX template

A template for estimating the annual OPEX budget is included in Appendix G. This template is for illustrative purposes only. The figures presented are notional and are not based on any real project. The granularity and presentation of OPEX budgets will vary depending on corporate policy, but the detail given in the template is adequate for the purposes of formulating an O&M strategy.

As discussed previously, the actual costs will vary greatly from project to project, and the staffing, equipment, and other expenses will differ considerably depending on the size, location, age, and other characteristics of the project.

6.3 Estimating CAPEX budgets

The CAPEX budget deserves special care and detailed planning (at least for major equipment) as it typically accounts for the largest share of the O&M budget. It covers nonroutine expenditure due to major refurbishment, rehabilitation, upgrade, and repair. It is typically presented as an investment schedule, with the costs shown in the year in which they will be incurred. For IPPs it is common to establish a major maintenance account to create a fund that can be drawn on as needed. The fund accrual is often tailored to suit the envisioned finance structure of new-build projects, with contributions to the fund growing as interest payments decline, resulting in an investment profile that increases with time.

Whether as a sinking fund or a schedule based on the in-year costs, the CAPEX investment plan needs to make adequate provision for the costs that are likely to be incurred. These include not only equipment purchases and construction/repair contracts, but any costs for studies, engineering, legal and regulatory services, and environmental and social measures.

CAPEX budgets should also include smaller capital items necessary to support the O&M function that are not included in the OPEX budget. These costs may include heavy equipment (cranes, bulldozers, backhoes, and other earth moving equipment), new buildings, housing or leasehold improvements, new large tools, machinery and equipment, new (not replacement) major spare parts, and replacement of small operating equipment. These budget lines are usually straightforward estimates with quantity and cost information being generally available. Some corporate policies include many of these items within the OPEX budget on the basis that purchases will be spread out and can be covered by the amortized allowance in the budget. Others make provision within the CAPEX budget to ensure that there is adequate financial provision in the year of purchase of these major items.

Two basic scenarios are considered hereunder for estimating CAPEX:

- **new-build project,** with costs based on the life expectancy of the major components
- **existing hydropower facility,** with a capital investment schedule based on the condition of the existing plant, and works

determined to be required in the initial diagnosis (Step 1).

As the purpose of this estimate is for validation of the O&M strategy, a high-level approach can be adopted. This would later be confirmed through detailed feasibility studies.

New-build CAPEX estimate

The various components of a hydroelectric facility are estimated to reach the end of their useful lives after different periods of service. This is illustrated in Table 6.1.

For new-build projects, it is assumed that these components will require major refurbishment or replacement at or near the end of their useful life. The CAPEX investment budget is based on the likely cost of the replacement or refurbishment. This can be based on the original cost or the component adjusted for inflation, but the percentage of original cost varies greatly depending on the component. Electronic equipment is typically budgeted at 100 percent of cost, since it is likely to be replaced in its entirety by updated equipment. Civil works, heavy mechanical and hydro-mechanical equipment may be budgeted at 25 percent of original cost, and other items in between, depending on how much of the original component is likely to be re-used.

TABLE 6.1 | Average life expectancy of plant parts and systems

PLANT PART OR SYSTEM	EXPECTED LIFE (YEARS)
Penstocks, gates, stop logs, trash racks	50–100
Main generation equipment: turbine equipment other than runners, generator, motor; governor, excitation system, and main inlet valves	30–40
Turbine runners Kaplan turbine Pelton turbine Francis turbine	Variable 30–60 40–70 25–40
Power transformers	40
High-voltage switchgear and switchyard equipment	40
Medium-voltage switchgear	30
Low-voltage switchgear	30
Plant auxiliary mechanical and electrical equipment (drainage and dewatering pumps, cooling system, compressed air system, ventilation and air conditioning system, AC/DC power supply, emergency diesel generator, etc.)	30
Seals, bushes, small fasteners, small valves, water strainer	15–20
Electronic devices and cards/controls, control and protection system, remote control, SCADA, communication equipment, metering	20, 15, or less
Painted surfaces	3–5

Source: Adapted from IFC (2016).

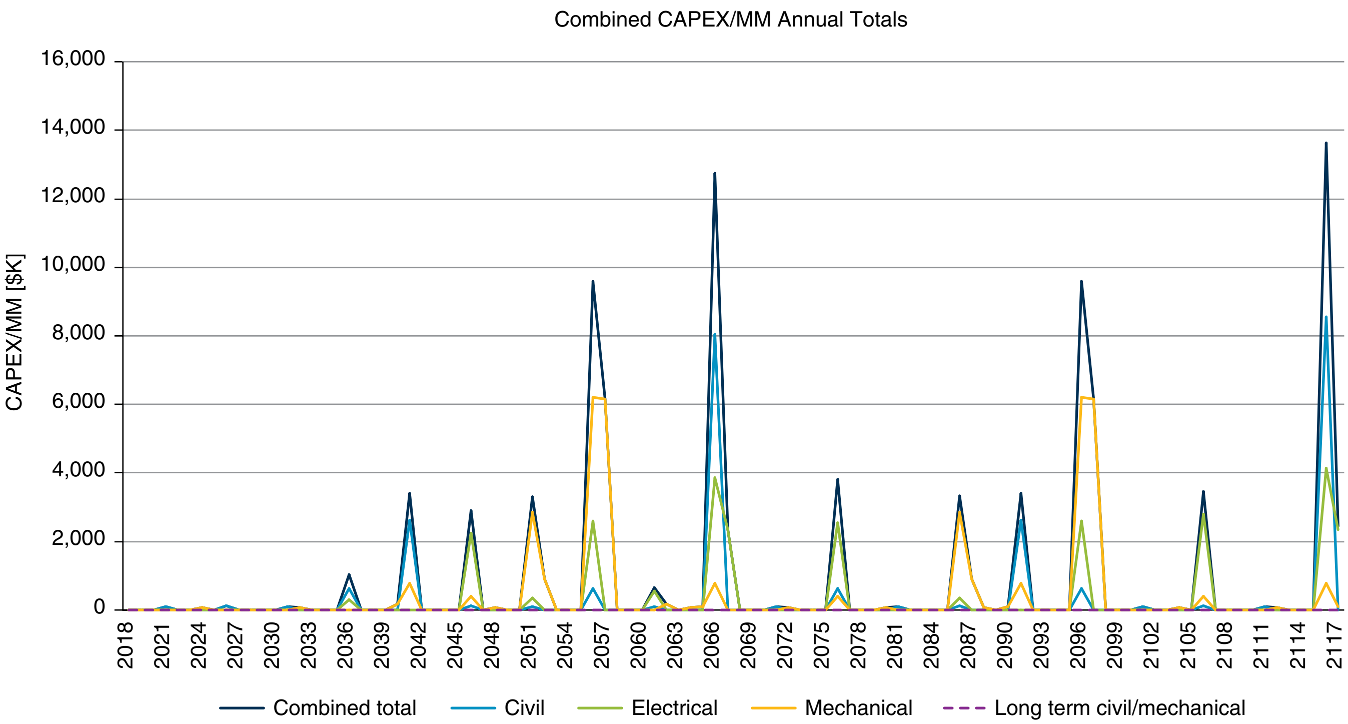
For stations with multiple units, it is common to budget for major refurbishment of one unit per year. This allows the costs to be staggered and makes optimum use of low-flow seasons to enable work to be carried out with minimal energy loss.

Figure 6.1 shows a 100-year CAPEX program designed for a 35 MW low-head hydropower facility in Canada, commissioned in 2016 with an initial investment of Can$150 million and a project life of 50 years. The CAPEX program budgeted for the first 50 years is Can$44 million (about 29 percent of initial investment costs), with most of the funds being spent at the end of the project life to refurbish for the next 50 years. It is interesting to note that it represents around one-third of the total scheme's investment (which is typically the cost of the electromechanical equipment of a hydropower scheme—the other two-thirds being civil works).

CAPEX estimate for existing facilities

For existing facilities, the CAPEX program will be based on the condition assessment undertaken in Step 1. The works will prioritize activities that rapidly deliver benefits, taking account of the financial capacity of the owner. Ideally, a full feasibility study with cost-benefit analysis would be undertaken to define and optimize the CAPEX program. This is unlikely to be carried out during

FIGURE 6.1 | Capital expenditure budget for a Canadian hydropower facility, 2018–2117



the selection of the O&M strategy, but at least a preliminary study should be carried out at this stage. At a minimum, it should include a high-level cost estimate based on an assumed schedule of refurbishment or replacement of life-expired equipment, using percentages of estimated new costs for the respective equipment.

6.4 Benchmarking

Benchmarking OPEX budgets

Benchmarking can be a helpful tool, but it should be used with caution and data should always be contextualized. Very limited benchmarking information is available for hydropower operating costs, and the available information is dated. The International Renewable Energy Agency (IRENA, 2012) benchmarks OPEX at 1–4 percent of construction costs (2–2.5 percent for large hydropower facilities and 1–6 percent for small facilities). Consultants typically use 1.5–2 percent as an average for OPEX on medium-sized facilities.

Figures 6.2 and 6.3 show the total specific construction cost ($/kW) of large and small hydropower facilities. OPEX can be estimated by applying the IRENA percentages to these construction costs. Based on an initial capital cost for a medium-size hydropower facility in Africa estimated at $2,500/kW, a 50 MW facility would cost an estimated $125 million to build, with estimated annual OPEX in the range of $1.25–5 million, according to IRENA.

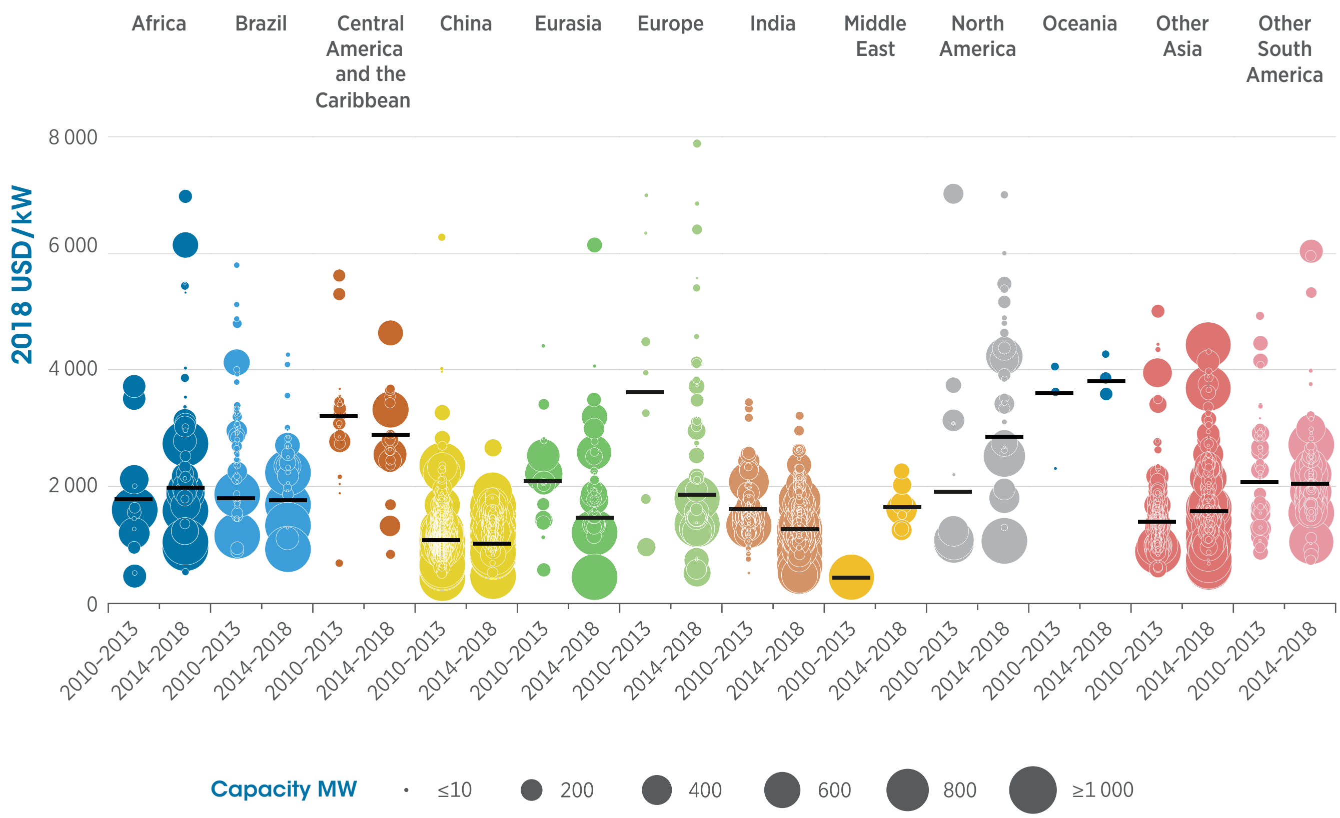
In 2003 the Idaho National Engineering and Environmental Laboratory (INEEL) developed cost-estimation equations based on a database of 2,155 hydropower sites in the United States (Hall, Hunt, and Carroll, 2003). The equation for OPEX is as follows:

OPEX (2002 US dollars) = fixed costs
$(A * [\text{capacity (MW)}]^B)$ *+ variable costs*
$(C * [\text{capacity (MW)}]^D)$
where A = 24,000, B = 0.75, C = 24,000, and D = 0.80.

The result needs to be increased based on the rate of inflation between 2002 and the current year.

Using INEEL's equation, a 50 MW hydro site would have estimated OPEX in 2018 of around

FIGURE 6.2 | Cost ranges and capacity-weighted averages for large hydros by country/region, 2010–2018



Source: © IRENA (2019). Used with permission from IRENA. Further permission required for reuse.
Note: Large hydropower projects in this figure are all those with capacity greater than 10 MW.

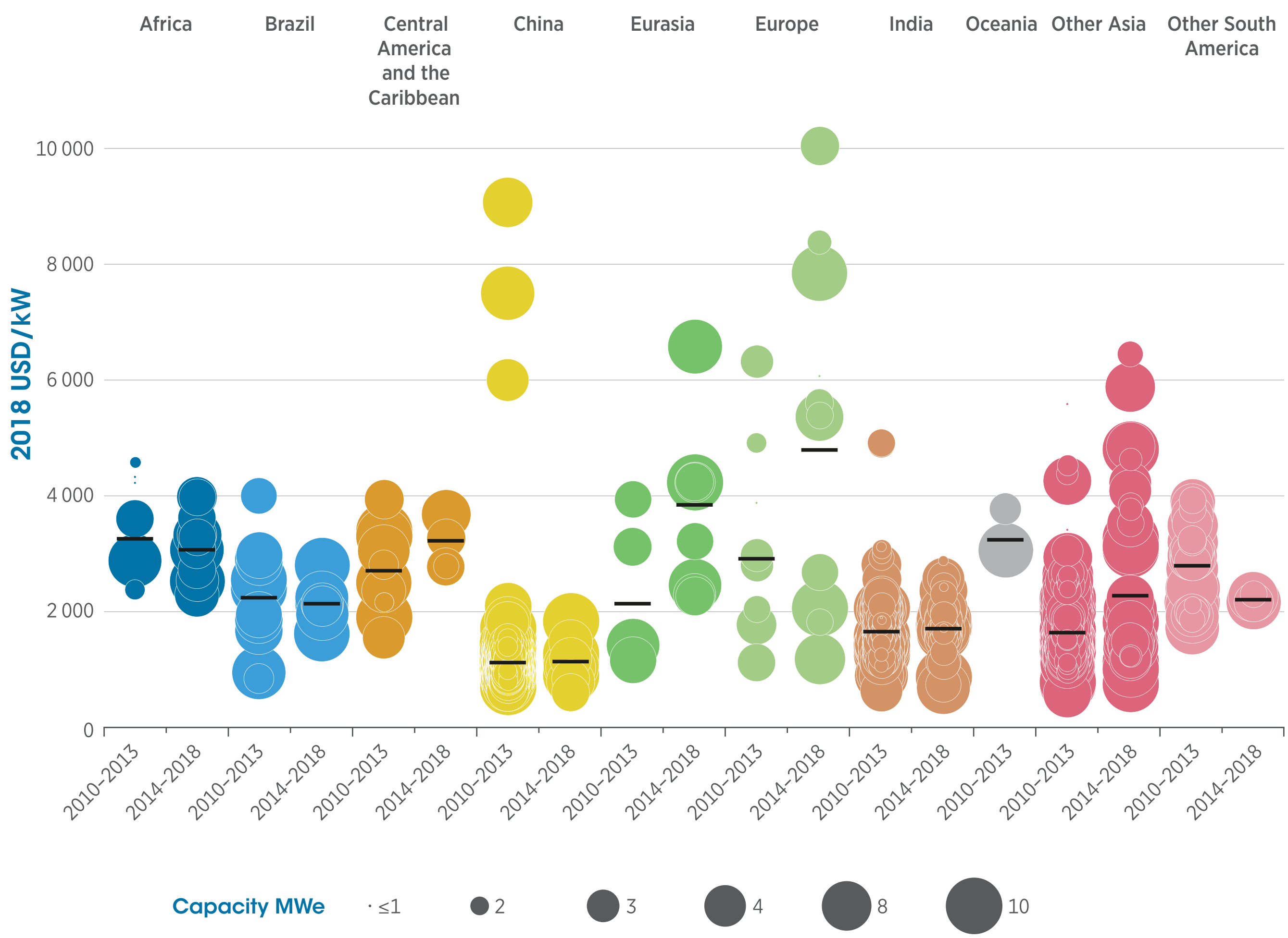
$1.5 million. This figure is at the low end of the range based on IRENA's benchmarking method. It seems likely that IRENA has included major maintenance and refurbishment costs in its estimates, accounting for the difference between INEEL and IRENA benchmarking methods. It is therefore recommended that IRENA's benchmarking approach, or the 1.5 percent to 2 percent of capital cost used by consultants, is used to benchmark the OPEX cost.

In the case studies summarized in the final chapter of this report and detailed in the companion report *Operation and Maintenance Strategies for Hydropower—Case Studies,* a wide range of budgets is illustrated, from less than 0.5 percent to around 1.5 percent of CAPEX investment value. This shows that O&M costs are dictated by the particular circumstances of each facility, including its location and the availability of suitably skilled local personnel to staff the facility. The use of percentage of construction CAPEX (or replacement cost) has its limitations, especially where local circumstances or the nature of the facility results in unusually high or low CAPEX. This is illustrated in Case Study 2 for Mount Coffee, where the reconstruction cost per MW is nearly double what might be expected elsewhere for a new project. However, the same factors, including lack of skills among the local workforce, also results in a high O&M cost.

Another indicator for benchmarking O&M costs is to consider the cost per kW/year, and the cost per kWh of energy generated. These indicators are presented in Table 6.2 for the case studies. The case studies are also summarized in the final chapter of this report and presented in more detail in the companion report *Operation and Maintenance Strategies for Hydropower—Case Studies*.

Table 6.2 illustrates some of the difficulties in comparing O&M costs. Companies have their

FIGURE 6.3 | Cost ranges and capacity-weighted averages for small hydros by country/region, 2010–2018



Source: © IRENA (2019). Used with permission from IRENA. Further permission required for reuse.
Note: Small hydropower projects in this figure are all those with capacity less than or equal to 10 MW.

TABLE 6.2 | O&M cost per unit of capacity and energy of case study facilities

SC NO.	ASSETS	CAPACITY	ENERGY	O&M COST	O&M COST/MW	O&M COST/MWh
		MW	GWh/YEAR	US$M/YEAR	kUSD/MW/YEAR	US$/MWh
CS1	Skanska Statkraft Assets in Brazil	188	959	5.80	32.22	6
CS2	Mount Coffee, Liberia	88	159	5.00	56.82	30
CS3	Kainji and Jebba, Nigeria	1,338	5,500	1.40	1.05	0.3
CS4	New Bong Escape hydropower project, Pakistan	84	470	2.75	32.74	5.9
CS5	Nalubaale and Kiira, Uganda	380	1,424	7.00	18.42	4.9
CS6	Salto Grande, Uruguay/Argentina	1,890	8,542	16.90	8.94	2.0

own methodologies for allocating costs to CAPEX and OPEX, and in some cases, the costs of centralized services and insurances are not included. For example, in the case of Kainji and Jebba (CS3), it is unlikely that the full O&M cost is included in the cost shown.

The benchmarking approach from IRENA or the consultant's typical 1.5 percent to 2 percent of capital cost may be used at the pre-feasibility stage, but for more detailed assessment a "bottom-up" approach, as described in section 6.2, is appropriate.

Benchmarking CAPEX budget

There is no reliable benchmarking information available for hydropower capital costs for replacement, refurbishment, or rehabilitation during the operations phase as these costs depend on many influencing factors. For new facilities, it is important to create a proper operation phase CAPEX plan prior to project financing so that proforma budgets include costs for future rehabilitations and replacements in accordance with expected life cycle of the equipment. Typically, the owner will create a long-term CAPEX budget along with long-term OPEX budget and use them in financial models for financing and tariff discussions.

In the absence of feasibility studies, the CAPEX estimates should be based on percentage of the component costs. For example, in a comprehensive refurbishment, 100 percent of the control, protection, and SCADA equipment might be replaced, and 30 percent of the turbine-generator units, but expenditure on the dam and civil works might only be 10–15 percent of its original cost. As a check, a major refurbishment program might cost around 25 percent of the overall original construction cost (escalated for inflation). Such a program is likely to be carried out over a period of years and is likely to start 25–30 years after commencement of generation.

6.5 Impacts of outsourcing (Models 2 and 3)

There is little information available to provide guidance on the budget for the outsourcing models (Models 2 and 3). However, some guidance can be derived by analyzing a breakdown of the costs of the services involved in undertaking the outsourced contracts.

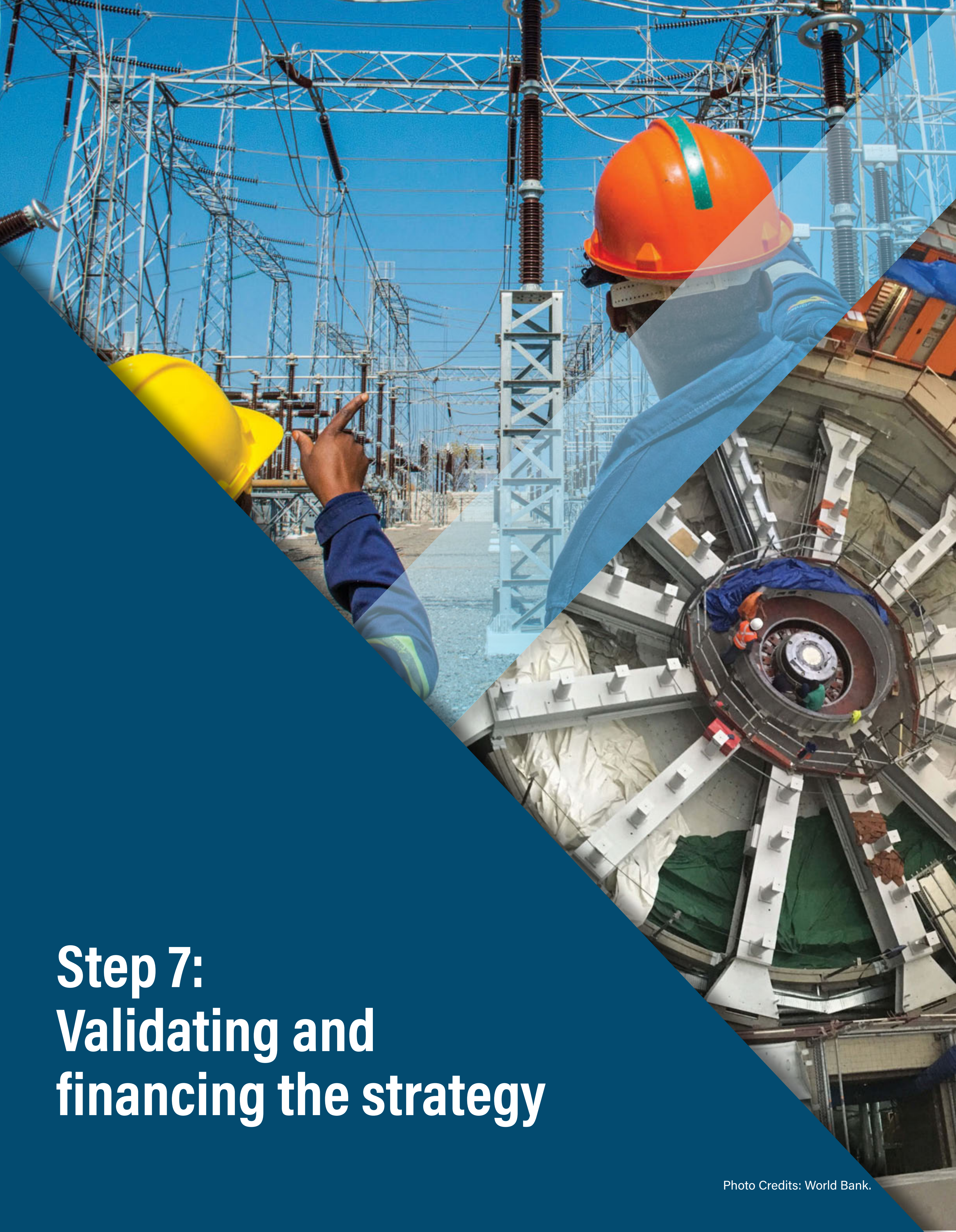
The cost of undertaking O&M contracts includes:

- **Cost of labor, equipment, and expenses:** this is essentially the same cost as would be incurred by the owner, although a private contractor may use a smaller team.
- **Cost of administration and overheads:** again, this is similar to that which would be incurred by the owner, although the owner or a fleet operator may be able to take advantage of economies of scale as a result of sharing costs across facilities.
- **Cost of risk:** this is dependent on the level of risk assigned to the O&M contractor. The risks in Model 2 are likely to be lower than in Model 3. In both cases, risks will depend on the penalty and bonus structure of the contract. The cost of risk in a poorly framed contract may exceed the other hard costs.
- **Recovery of investment costs:** this amount will depend on how much the contractor is required to invest, and the cash flow under the payment terms. Contractors charge a high premium if their income does not closely match their expenses.
- **Profit:** the operator will expect a reasonable profit in the range 10–20 percent of the contract value.

Bearing in mind these factors, it should be possible to produce contract terms where the cost of outsourcing is within the 150–200 percent range of the cost of providing the services in-house. While this may seem a high price to pay, the additional cost can easily be recovered through increased revenue and reduced outages. It is possible to make much of the increased cost contingent on achieving a significant uplift in the revenue, so that the outsourced O&M pays for itself.

THE OUTPUT FROM STEP 6

Are the cost estimates of OPEX and CAPEX planned under the proposed O&M strategy? These cost schedules will be used in the cost-benefit analysis to validate the strategy and check whether the proposed strategy is sustainable and bankable.



Step 7: Validating and financing the strategy

Photo Credits: World Bank.

In Step 7, the proposed O&M strategy is analyzed and validated. The primary method of validation is economic cost-benefit analysis using the estimated costs derived in Step 6 and the expected economic benefits from Step 2. If the cost-benefit analysis does not achieve a satisfactory hurdle rate, an iterative loop back to Step 2 is proposed, to repeat the process until satisfactory balance or marginal benefits are reached. This step also includes a check that adequate funding will be available.

7.1 Cost-benefit analysis

In order to validate the O&M strategy, economic cost-benefit analysis is undertaken to ensure that the benefits derived from the strategy exceed the costs of implementing the strategy.

It is important that for both cost and benefits, the incremental values of implementing the strategy are captured. In the case of costs, it is the incremental costs (in excess of the BAU case for existing facilities) that should be used. For benefits, the uplift in benefits associated with implementation of the strategy is used. If marginal calculations are not feasible, the balance/financial equilibrium of the overall utility's business model will be checked.

Validation of the O&M strategy requires a simple spreadsheet-based model. The net present value (NPV) of the cost stream (negative values) and the benefit stream (positive values) are calculated. If the NPV is positive, it demonstrates that the time-weighted value of the benefit stream exceeds the time-weighted value of the cost stream, and hence the investment is yielding positive returns.

The same model can be used to present the benefit/cost ratio of the investment, which, if greater than one, indicates positive returns on the investment.

Care is needed in selection of the discount rate. Use of a high discount rate quickly reduces the value of future benefits and tends to make capital investments look unprofitable. However, the use of an unrealistically low discount rate will show such investments as being profitable, when in reality the cost of capital renders the investment to be uneconomic.

A discount rate of 6–8 percent is recommended, with costs and benefits in constant prices. This should reflect the weighted average cost of capital (WACC) for many owners. Sensitivity analysis can be carried out around this number to assess whether the analysis is robust.

In the event that the cost-benefit analysis does not validate the proposed O&M strategy, alternatives should be investigated, starting at Step 1 to ensure that a robust strategy delivering positive benefits is selected.

Private-sector owners may also carry out a financial analysis, evaluating the costs of operating the facility with and without the implementation of the O&M strategy, taking into account financing costs and expected revenue streams. The financial indicators used to justify the investment will vary from company to company, but the O&M strategy will be expected to show improved financial returns compared with the business-as-usual case, if it is to be adopted.

7.2 Financial/funding assessment

In order to determine the financial viability of the proposed strategy, the costs estimated in Step 6 should be inserted into the financial business model of the utility to check that financial resources will be available at the required time to fund the proposed strategy.

If this proves not to be the case, discussions on budget allocation/prioritization within the overall structure may need to take place and financing options may have to be explored to balance the financial model. Such options could include, among others, the mobilization of subsidies from the sector or loans that will allow the gap between returns from investments and expenditures to be bridged.

In case such analysis demonstrates that the electricity tariff level or structure is the root cause of failing to balance the model, communication, and representation should be made to the agency responsible for tariff setting to achieve tariffs that will enable sustainable operation and maintenance of the hydropower fleet.

In order to reduce the burden of major CAPEX expenditure on the owner's balance sheet and financial model, these activities could also be externalized and funded as separate projects (with the support of local or international funding). Debt financing from local private banks could also be used with the support of guarantees from development banks or other development agencies.

Escrow accounts are often established to hypothecate revenue from major off-takers, to ensure that the revenue is available to be used for O&M, either to cover the owner's OPEX costs under Model 1, or to provide payment security under Models 2 and 3.

Finally, in order to support allocation of adequate funding and budget allocation, a presentation may need to be made to decision makers on the potential costs and implications of poor O&M practices, as presented in the introduction.

7.3 Validation of the strategy

At this point in the process, the main outputs from all previous steps should be brought together in a comprehensive report that will record key analyses and outcomes including:

- diagnosis of existing state
- strategic objectives for future situation
- selection of activities to reach these objectives
- selection of O&M model to effectively implement these activities
- identification of staffing and capacity-building requirements
- cost estimate for implementing the strategy
- funding and cost-benefit analysis.

Consultations will then need to take place to inform and obtain buy-in from all stakeholders. The report may be issued to solicit feedback and comments from internal stakeholders and managers, so that they validate the reasonableness of the findings. Where required or relevant, external consultation will also be implemented.

Once the strategy is validated, targeted communication documents may be prepared to disseminate key messages within the owner's organization and other stakeholders.

THE OUTPUT FROM STEP 7

Will be collation of the inputs and validation of the O&M strategy, including cost-benefit analysis and identification of funding sources for the investments required.

Step 8: Implementing the strategy

Photo Credits: (Top left): World Bank.
(Bottom right): Babar Khan.

Having validated the O&M strategy in Step 7, guidance on the implementation of the strategy is provided in this Step. This guidance covers detailed operating plans, contracts, agreements, finance mechanisms, and monitoring procedures.

8.1 Supporting contracts and agreements

Once approved, the O&M strategy is implemented by the owner using internal resources and appropriate agreements and contractual arrangements.

The terms and conditions in the O&M contract will need to reflect the obligations of the owner under its concession agreement and PPA in the case of an IPP, or the requirements of the electricity regulator in the case of a public utility.

A key issue for the O&M contractor will be the security of payment for its services. Many public utilities in developing countries have poor credit ratings. Guarantee mechanisms, such as partial risk guarantees, may be required in order to provide security of payment.

Escrow accounts provide a particularly effective mechanism of payment security for O&M contracts. Rolling one-year escrows may be funded out of revenues of the facility. In the event that the owner fails to maintain the account, the O&M contractor has one year of funded operation during which the account may be replenished. If the account fails to be replenished, the contractor can demobilize.

Other methods for underwriting the owner's payment obligations are set out in Table 8.1.

TABLE 8.1 | Contractual arrangements to legally frame implementation of the O&M strategy

ARRANGEMENTS	CONCESSIONAIRE/ PRIVATE OPERATOR	PARASTATAL UTILITY
Concession agreement and power purchase agreement	✓	
Partial risk guarantees	✓	✓
Sovereign guarantees	✓	
Allocation of responsibilities with respect to upstream/ downstream water resource management jurisdiction, environmental issues, and social responsibilities arising out of the project development	✓	✓
Employment and training requirements for localization of positions	✓	
Recruitment and training programs	✓	✓

8.2 Annual operating plans (including five-year capital program)

Once the O&M strategy has been formulated and contractual provisions for implementation have been completed, the owner will need to proceed with preparation of a detailed annual operating plan that will describe how the strategy will be implemented. Annual plans will describe the operation activities to be undertaken on a daily, weekly, monthly, quarterly, and annual basis. The subsequent operating plan will also include activities required to implement the O&M strategy (internal activities, consultancies, training, etc.). Longer-term plans will cover the activities over subsequent years. It is expected that these plans should be updated annually on a rolling basis.

In order to develop a plan that suits the requirements of the grid, discussions with the electricity system operator, off-taker, and possibly the regulator will be required, so that maintenance outages can be timed for minimum disruption and coordinated with other generators. The communication requirements for this will normally be specified in the concession agreement, PPA, or grid code.

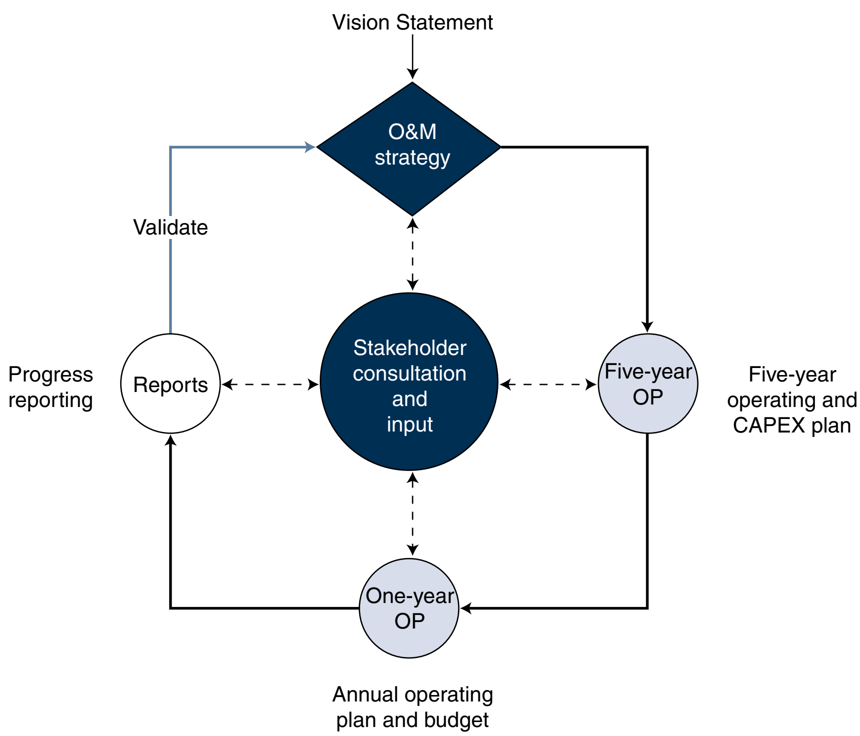
In addition to the annual O&M plans, a capital works program is required to schedule the non-routine capital-investment activities. This plan will typically cover a five-year period, setting out activities and expenditure during this period. A more-detailed one-year capital plan will set out, on a daily basis, the activities to be undertaken during the coming year and will be integrated in the above-mentioned annual operating plan.

The operating plan is used to communicate the organization's goals for the coming years, the actions needed to achieve those goals, and all other critical elements developed during the planning exercise. This annual planning process follows a method similar to that described in Steps 1 to 6.

Figure 8.1 provides an example of an annual planning process.

The operating plan is a management tool that facilitates the coordination of the organization's resources (human, financial, and physical) so that goals and objectives in the strategy can be achieved (Isaac, n.d.).

FIGURE 8.1 | Typical annual planning process to implement the O&M strategy



Source: Adapted from ICANN.org (2015). https://www.icann.org/resources/pages/operating-plan-budget-2015-06-12-en

In Table 8.2, the differences between the O&M strategy and the operating plan are described.

TABLE 8.2 | Difference between a strategy plan and an operating plan for O&M

O&M STRATEGY	OPERATING PLAN
A general and strategic guide for O&M management.	A specific plan for the use of the organization's resources in pursuit of the strategic plan.
Suggests strategies to be employed in pursuit of the organization's goals.	Details specific activities and events to be undertaken to implement strategies.
A plan for the pursuit of the organization's mission in the longer term (three to five years, or even longer).	A plan for the day-to-day management of the organization (one-year time frame).
Enables management to formulate an operational plan.	An operating plan should not be formulated without reference to a strategic plan.
The strategic plan, once formulated, tends not to be significantly changed every year.	Operating plans may differ significantly from year to year depending on changing O&M circumstances.
The development of the strategic plan is a shared responsibility and involves different categories of stakeholders.	The operating plan is produced by management of the organization and approved on an annual basis for directing activities for the current operating year.

Source: Isaac (n.d.).

The operating plan shows:

- **what:** strategies and tasks that must be undertaken
- **who:** people who have responsibility of each of the strategies and tasks[19]
- **when:** timelines in which strategies and tasks must be completed
- **how much:** financial resources are needed to complete each strategy and task.

The operating plan is both the first and the last step in preparing an O&M annual budget. As the first step, it provides a plan for resource allocation; as the last step, it may be modified to reflect policy decisions or financial changes made during the budget-development process.

The operating plan is prepared with inputs from all entities involved in O&M. It can be limited in scope to looking at a single facility or multiple facilities, depending on the structure of an organization. Operating plans work for both in-house management of O&M and outsourced O&M or any combination of the two. In case of outsourcing major responsibilities, contracted operators should deliver and share such comments to the owner for feedback (and validation if required in the contract).

In order to implement the plan, it is necessary to establish a detailed O&M budget. The typical O&M budget process begins three to four months before the end of the year. Figure 8.2 shows a typical timeline for this process with a sample fiscal year starting January 1.

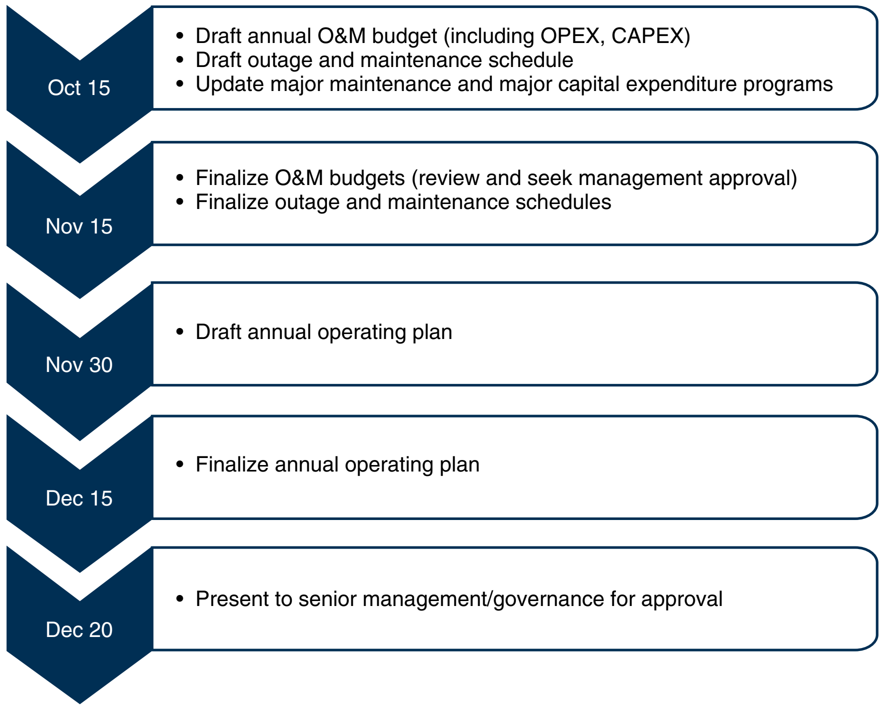
8.3 Monitoring implementation of the strategy

The last step is to put in place mechanisms to capture data on a continuous basis in order to inform management on progress in meeting the objectives of the O&M strategy and operating plan. This is normally undertaken through measurement and monitoring of KPIs and preparation of monthly and quarterly reports. Analysis of the reported KPIs enables decisions to be made on the success, or otherwise, of the O&M strategy, so that continuous adjustments may be made.

Many of the KPIs are only meaningful once several years of records are available. Hence initial assessment of success of the operator will need to be based on the operator's approach and methodology, and assessment of the operator's

[19] For this purpose, a RACI responsibility matrix could be developed as mentioned at the end of Step 3.

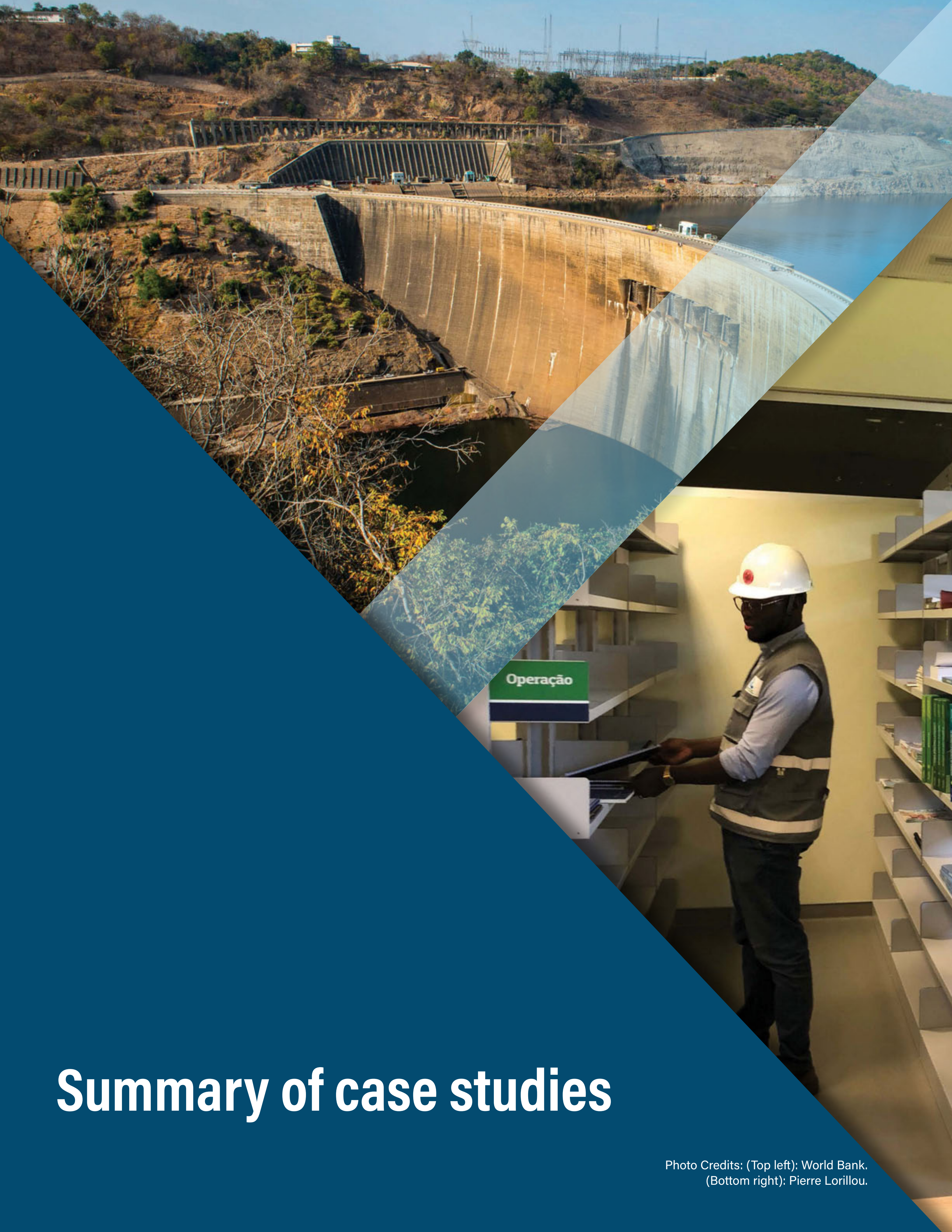
FIGURE 8.2 | Sample timeline of annual operating plan



performance in carrying out the services in compliance with his obligations under the O&M contract. Later, when the KPIs are based on sufficient length of record, they can be compared with the targets in the strategy and with industry norms.

THE OUTPUT FROM STEP 8

Include the documentation required for implementation of the O&M strategy. The documents include the supporting contracts and agreements, the five-year capital program, the annual operating plan, and the monitoring plan, including the KPIs that will be measured and included in regular reports.



Summary of case studies

Photo Credits: (Top left): World Bank.
(Bottom right): Pierre Lorillou.

Case studies hereunder showcase different models for implementing O&M strategies and illustrate practically some of the recommendations and good practices described in this handbook. These six case studies (Table 9.1) have been prepared with public utilities and private companies and are structured around the key steps and topics covered in the preceding steps, including strategic models, management of human resources and financial aspects. They also bring lessons learned from the implementation of O&M strategies that had been chosen and applied, while sharing views on remaining challenges and future directions.

The case studies illustrate the options available under these models, including facilities like Statkraft in Brazil (Case Study 1), where major improvements were achieved through transition from Model 3 to Model 1. Mount Coffee in Liberia (Case Study 2), illustrates a strategy where Model 3 is adopted as an interim measure while training is provided to enable the utility to revert to Model 1.

The following subsections summarize each case study while further details are provided in Appendix H: Detailed Case Studies.

9.1 Statkraft Energias Renovaveis, Brazil

In July 2015, Statkraft took over control of the Statkraft Energias Renovaveis (SKER) Brazilian company, increasing their shares up to 81.31 percent, in partnership with FUNCEF, a Brazilian pension fund (18.69 percent). SKER is an existing company with almost 316 MW installed capacity, of which 128 MW is onshore wind generation and 188 MW is hydropower generation. SKER has successfully operated six facilities (180 MW) at an average availability of 97.7 percent over the last three years (2015–17). This

TABLE 9.1 List of case studies and models adopted

CASE STUDY	COUNTRY	NAME	INSTALLED CAPACITY—MW	MODEL	KEY FEATURES
1	Brazil	Statkraft's Assets	180 MW (six facilities)	1	O&M taken in-house and Statkraft's systems adopted
2	Liberia	Mount Coffee	88 MW	3	Interim measure while staff are trained to implement Model 1
3	Nigeria	Kainji and Jebba	1,338 MW (two facilities)	2	Most O&M activities by the owner, but some specialist activities outsourced
4	Pakistan	New Bong Escape hydropower project	84 MW	3	Notionally Model 3, but outsourced O&M is now undertaken by a subsidiary of the owner, so similarities to Model 1B
5	Uganda	Nalubaale and Kiira	380 MW (two facilities)	3	Fully outsourced concession
6	Uruguay/Argentina	Salto Grande	1,890 MW	1	O&M by the in-house team

is considered to be an optimum level for these hydropower assets.

In 2015, the O&M model was structured with limited ownership representation, and outsourced management and execution (Model 2). By 2017 it transitioned to a model with full ownership control, with management and execution carried out in-house (Model 1). This aligned the O&M processes with Statkraft's business plan and its long-term goals.

SKER's O&M strategies focus on operating on a commercial basis with profitability as a key objective, ensuring that health, safety, and human rights of employees are valued and protected.

The occupational health and safety system is aligned with the guidelines in OHSAS 18001 and ISO 14001 or equivalent national standards and regulations. Efficient use and development of expertise and continuous improvement processes underscore SKER's O&M program.

The in-house human resource planning process deployed within SKER evaluates workers from a technical perspective and potential for career progression in the Statkraft Group. To optimize O&M staffing, a maintenance optimization process was implemented, based on the TSW O&M model, resulting in a significant reduction in the maintenance workload.

The financial resources allocated annually to the company's O&M program are primarily based on the corporate energy management plan, which in turn is defined largely by basin hydrology and market conditions. Once the financial resources are allocated, an annual energy production forecast is prepared. Thereafter, the O&M work plan is prepared, based on the condition of assets and a risk and vulnerability assessment that includes a 360-degree risk process. The long-term and short-term planning processes take into account operational conditions and maintenance requirements and determine the OPEX and CAPEX resources necessary to fulfil the company business plan. The annual O&M budget is allocated at the plant level, including all O&M expenses, administrative and financial requirements, and overhead, commercial, and tax expenses. In Statkraft Brazil, each plant functions as an individual company in order to optimize benefits.

The Weighted Maintenance Object[20] (WMO) benchmarking model, developed by Statkraft and PA consulting in 1989, was applied in South America and Asia over the last decade, improving the performance of their assets. The model rates hydropower assets based on technical and OPEX-CAPEX expenditures from high cost to low cost, to improve efficiency and reduce operating costs. Guidance from the WMO method reduced the yearly OPEX by 3.7 Million USD, representing a 40 percent reduction of the annual O&M budget across all six facilities. SKER's facilities are among the most efficient of Statkraft's assets, when compared using the WMO benchmarking system.

Challenges faced by SKER in the coming decades include managing O&M costs to ensure cost competitiveness, further applying Statkraft corporate contract and business models, and the need to adopt digitalization solutions for revenue optimization and cost reduction through automation and smarter O&M.

9.2 Mount Coffee Hydropower Project, Liberia

The Mount Coffee hydropower project in Liberia has been fully restored, with a new four-unit, 88 MW powerhouse coming online between

[20] Technical infrastructure complexity is reflected in the WMO number. To compare companies with significantly different technical infrastructure, there was a need to normalize the comparison. Comparing technical infrastructure and related costs enables benchmarking of execution and effectiveness within different regions.

2016 and 2018, after the plant had been partially destroyed and totally disabled through years of civil unrest. After the facility was destroyed in the early nineties, Liberia Electricity Corporation (LEC) lost its in-house experience and expertise for operating the facility. In 2016, LEC signed a five-year operations, maintenance, and training (OMT) contract with a Swiss firm, Hydro Operation International (HOI) to operate and maintain the Mount Coffee hydropower facility while providing theoretical and hands-on training to LEC's Liberian O&M staff. This training covers plant management, operations, maintenance of generation equipment, and other associated skills.

Operation of the Mount Coffee Hydropower station is focused on maximizing availability by ensuring that best practices and standards are incorporated into the daily operation and maintenance of all utility components (e.g., spillway, intake, production units, controls, etc.) and in the training of 18 local staff by the contractor, HOI.

Maintenance strategies are developed on the basis of regularly scheduled inspections of key components and systems, with replacement or repair of parts whenever required. Minimizing outage time and forced outages is achieved through planned inspections of all equipment (serviceable and non-serviceable) to establish condition and to identify potential risk of failure.

Training of staff is designed to ensure that an adequate transfer of skills is achieved through the five-year period. The following describes staffing arrangements:

- The management team, under the responsibility of an experienced plant manager, is staffed by HOI, with an LEC counterpart assigned to each position.
- Operations staff are comprised of HOI shift supervisors, each with an LEC counterpart. A second generation of LEC trainee staff has been added recently to prepare for completion of the first-generation training program, after which the HOI staff will leave the site. It is anticipated that after three years of training, the operation shifts will be solely staffed by LEC personnel.
- Maintenance staff, under the responsibility of HOI senior staff, each have a position matched with an LEC counterpart trainee.

Some of the challenges with this ongoing O&M arrangement have included: retention of newly trained staff, lack of funds for day-to-day operation and maintenance, lack of reserve funds to cover major maintenance works and future overhauls, operating issues related to grid instability, and challenges managing low inflows during the dry season due to the lack of a storage reservoir.

O&M has been hampered through not including some of the infrastructure required for efficient O&M in the original refurbishment budget. Electricity production is currently constrained by demand, and hence revenue is insufficient to procure this infrastructure.

Looking ahead, HOI has suggested that a specific O&M company with its own management, financial, and operational targets and sources of revenue might be a more optimal O&M strategy, which could guarantee the performance, reliability, and sustainability of the plant over the longer term.

9.3 Kainji-Jebba Hydropower Complex, Nigeria

Mainstream Energy Solutions Ltd. (MESL) took over the 1338 MW Kainji-Jebba hydropower complex on November 2013. At the time of acquisition, the Jebba plant was operating at 460 MW, while the Kainji plant was completely inoperable. To date, under their ongoing capacity recovery plan (CRP), MESL has restored over 69 percent of the installed capacity of the Kainji-Jebba complex to 922 MW. MESL has improved the performance of the combined system, with availability rates exceeding 99 percent over the period 2014 to 2018, and a forced outage rate of only 0.53 percent.

Before privatization of the power sector, Nigeria operated a vertically integrated power utility. Under the public governance model, hydropower facilities were operated with a lack of well-defined O&M strategies, and a focus only on energy production, resulting in poor maintenance and a lack of safety and environmental practices. Under this model, the Nigerian power sector suffered persistent power outages and unreliable service, which compelled the government to privatize the unbundled National Power utility in an effort to achieve a stable and adequate supply of electricity at a reasonable cost.

MESL was incorporated and licensed as a power generating company in 2011, acquiring the Kainji and Jebba hydropower facilities through a 30-year (2013–2043) concession agreement with the government of Nigeria. Under this arrangement, O&M is in the hands of the private owner/concessionaire, MESL. MESL employs prudent management to ensure the company prioritizes and achieves its annual financial targets and minimizes costs. MESL strives for continuous improvement in its overall O&M strategies by utilizing the Deming's (PDCA) cycle concept and by benchmarking its O&M program against world-class standards through key performance indicators (KPIs) measuring plant availability and reliability. MESL monitors the performance of its facilities, with safety as a priority, and with targets of zero accidents and no environmental damage, while optimizing reliability and energy production.

Some of the challenges MESL has experienced in implementing their O&M program include:

- non-compliance with market rules by some market participants
- instability in the Nigerian electricity market
- grid instability issues leading to accelerated equipment wear
- water resource management challenges related to greater climate extremes
- difficulties in sourcing spare equipment due to obsolescence
- conflicts of interest with the downstream water users and riparian communities
- emergence of a more competitive electricity market.

MESL has implemented measures to achieve continuous improvement in their O&M program through the implementation of a computerized maintenance management system (CMMS), and utilizing reliability centered maintenance principles (RCM), with a target of achieving certification ISO 9001. MESL is working to improve its water management strategies through an optimized inflow forecast system, to produce more accurate generation projections and an improved flood warning system.

MESL has instituted a recruitment and retention program to encourage promotion within the organization and facilitate knowledge transfer. This has been achieved through a number of training programs, e.g, leadership training for middle managers as part of succession planning, and power plant operation and maintenance training for O&M personnel at both local and international levels, etc. Recruitment is assisted by a national technical institution NAPTIN (National Power Training Institute of Nigeria).

9.4 New Bong Escape Hydropower Project, Pakistan

Laraib Energy Limited (LEL) is a subsidiary of the Hub Power Company (HUBCO), the first hydropower Independent Power Producer (IPP) in Pakistan, and owner and developer of the 84 MW New Bong Escape (NBE) Hydroelectric Power Complex on the Jhelum River in Azad Jammu and Kashmir (AJ&K). HUBCO owns

75 percent shares in LEL and has a portfolio of over 2,900 MW within the country.

Laraib Energy Limited owns the 84 MW NBE hydroelectric power plant, developed under the Build-Own-Operate-Transfer (BOOT) mechanism. The facility will be transferred to the government of Azad Jammu and Kashmir (transferee) at the end of a 25-year term.

Laraib Energy Ltd. had initially signed an O&M agreement with TNB REMACO Pakistan in May 2011 to operate the facility in accordance with the lender's requirements. This agreement was terminated in March 2018, after which the Hub Power Services Limited (HPSL), a private sector O&M company and a wholly owned subsidiary of HUBCO, took over the role of O&M operator.

The O&M strategy for NBE is notionally aligned with Model 3, with virtually all of the O&M responsibilities outsourced under an arm's-length contract. However, since the O&M contractor is a subsidiary of the owner, the strategy shares many similarities with Model 1B.

NBE is the world's first hydropower facility to be implementing the globally renowned DuPont Safety Management System and is the first hydropower project in Pakistan registered with the United Nations Framework Convention on Climate Change (UNFCCC) as a Clean Development Mechanism (CDM) project. The NBE hydropower complex has maintained availability levels at greater than 98 percent for the last three consecutive years.

A total of sixty-nine staff, comprised of the Station Manager and Head of O&M, seven section managers and sixty O&M staff work at the plant site. The O&M team reports to the Plant Manager and is comprised of seven departments: Health, Safety, and Environment; Operations and Maintenance; Projects and Engineering; Human Resources; Finance; Business Support; and Administration.

Training requirements are assessed annually for technical and soft skills development. Specialized skills are developed through reliability centered maintenance (RCM) training organized on-site for operators and technicians. LEL has signed a technical services agreement (TSA) with Andritz Hydro, which provides access to training related to hydropower facilities, knowledge and learning sessions, sharing of root cause analysis, and improvement projects carried out at similar facilities.

An annual plan is submitted by the O&M operator to the owner/concessionaire and an operating budget is prepared, with final approval by the lenders and the board of directors. At the end of the year, the annual budgets are reconciled against quarterly expenses and compared against the annual plan approved at the beginning of the year. The annual plan incorporates the anticipated plant improvement projects. The O&M budget typically ranges between 2.5 to 3.0 million USD per annum which represents 1.1–1.3 percent of the construction cost.

Discussions are underway with global automation leaders to devise a predictive approach to address aging of plant equipment in a proactive manner, which could improve reliability using expert diagnostics and predictive analytics, resulting in early warning detection of equipment failure, avoiding unplanned outages, and providing better risk management.

9.5 Nalubaale-Kiira Hydropower Complex, Uganda

Uganda Electricity Generation Company Ltd. (UEGCL) has executed a 20-year concession with Eskom Uganda Limited (EUL) for operation, management, and maintenance of the Kiira and Nalubaale power stations. Eskom sells the electricity it generates to the Uganda Electricity Transmission Company Limited. The agreement will be in place until 1st April of 2023.

Currently, the Kiira and Nalubaale power stations have a combined capacity of 380 MW. Availability for the Nalubaale and Kiira complex has been maintained from 94–97 percent, and the combined annual energy production is on average 1,424 GWh per year.

The general O&M policy adopted by EUL for maintaining the Nalubaale-Kiira hydropower complex is comprised of two maintenance cycles. The first is a general maintenance and overhaul completed during a 30-day planned outage on a 36-month cycle for each unit. The second are more detailed inspections completed during a 15-day planned outage on an 18-month cycle for each unit subsystem, to establish the condition of each unit. The success of the O&M program is measured using a set of performance metrics that include availability, reliability, lost-time injury rate, oil spills, waste disposal, water quality, security, and annual profits.

EUL introduced a recruitment program offering a three-year training program for up to 10 trainees at each of the two sites, Nalubaale and Kiira HPP. This program has been successful at facilitating knowledge and skills transfer to internal staff. Exposure to the parent company is provided, with assignments under the supervision of senior personnel.

Planning for financial resources to support the annual O&M plan is the responsibility of the concessionaire, who submits an application for generation O&M costs for a given period, indicating details of the maintenance to be carried out and the technical plan for that period. This application is reviewed by UEGCL and UETCL and is then issued to the regulator for approval.

Challenges faced under the current concession arrangement include (i) lack of contractual performance measures instituted by the concessionaire with a focus on asset management and (ii) skills retention.

9.6 Salto Grande Hydropower Complex, Uruguay/Argentina

The Salto Grande Complex (SGC), located a few kilometers upstream from the cities of Concordia (Argentina) and Salto (Uruguay), is comprised of 14 Kaplan turbines rated at 135 MW per unit for a total installed capacity of 1,890 MW. Average annual availability was 94.3 percent in 2017 and 95.6 percent in 2016, with an overall average availability of 93.4 percent from 1983–2017.

The Salto Grande Complex is a binational facility with the site and equipment jointly owned by Uruguay and Argentina and the energy generated divided equally between both countries. Because of this unique arrangement, Salto Grande operates in an integrated coordination between two separate load dispatch centers, with operation and maintenance processes carried out with a binational team.

SGC utilizes the Infor-EAM[21] enterprise asset-management system to improve productivity, safety, and efficiency across the organization; to optimize asset records; perform asset-intervention analysis; and to ensure environmental and human safety while decreasing time and costs in work and license permits for workers. These EAM processes are complemented by reliability-centered maintenance (RCM) analysis of critical equipment, HydroAMP-condition assessment, and external evaluations made by turbine and generator manufacturers. Since 2003, SGC has embarked upon a multiyear modernization project to update major assets such as primary breakers and unit-excitation systems, protections systems, sluice gates, and other key components. A 20-year plan for modernizing the other major components will include

[21] For more information, see link: https://www.infor.com/content/casestudies/salto-grande.pdf/

digitalization of control and supervisory systems and integration of all control and monitoring equipment.

Currently the SGC complex employs over 300 O&M personnel, comprised of 84 maintenance staff and 66 operating staff, together with other staff involved in maintenance of the transmission system and operation planning. Maintenance training is offered to staff on certification of crane operators, certification of welders, and a number of other key skills. Operational training is undertaken by pairing new operating personnel with experienced operators for a period of at least five months. Although there is no formal succession planning strategy, knowledge transfer is achieved through internal workshops, led by experienced staff on specialized systems.

Governance of O&M budgets within SGC is achieved with representatives from each country. The overall budget is approved on an annual basis. Common costs, including staff salaries, investments and other common expenses, are financed in equal parts by each country.

The financing of the first five years of the multiyear modernization program at SGC has been obtained through loans from the Inter-American Development Bank. The financing of a longer-term modernization program, to cover the 20-year period from 2024 to 2043 will be addressed in the next five years with governments, international financial entities, and suppliers.

One of the more significant challenges facing SGC in coming years will be the planning and coordination of the O&M processes during the plant modernization. Human resources assigned to this project will need to strategically integrate and communicate parallel activities such as writing specifications, working with consultants, testing, and commissioning.

Appendixes

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Appendix A: O&M glossary

Ancillary services: the capacity and energy services provided by power plants, such as hydropower plants, that are able to respond on short notice, ensure stable electricity delivery, and optimize grid reliability.

Capital expenditures (CAPEX): the investment associated with refurbishment, rehabilitation, replacement, and purchase of equipment or major spare parts.

Concession: a public-private partnership (PPP) arrangement in which the private and public sectors share risk. Normally a long-term arrangement of at least 20 years is granted by the government to a special-purpose or private company, in which the government or parastatal utility may or may not be a shareholder. The concessionaire is granted ownership rights and responsibility for implementing, operating, and maintaining the facility for the concession period. The operator is free to operate and maintain the facility to obtain the desired/agreed return on investment within the constraints of the concession agreements, which details legal, employment, environmental, and social obligations. The concessionaire can also be asked to rehabilitate and refurbish some equipment, which turns the concession into a rehabilitate, operate, and transfer (ROT) model. A concession agreement should also detail the expected status of the plant at the end of the concession.

Condition-based maintenance: is based on the results of inspections, alarms, and the monitoring and analysis of the behavior of equipment and structures during normal operation. Where degradation of equipment is likely to lead to failure or inefficient generation, maintenance, repair, and refurbishment measures are deployed.

Corrective maintenance: is carried out after a breakdown for the purpose of restoring an asset to a condition in which it can perform the required function.

Failure modes: include security, dam, environmental, regulatory, and economic failure modes.

Fleet: single or several hydropower facilities under single ownership.

Hydropower O&M: refers to all activities needed to run and maintain good physical and operational statuses of hydropower facilities (excluding replacement or construction of new facilities). It usually includes the rehabilitation of existing components and maintenance overhauls.

Independent power producer (IPP): a nonpublic, nonutility generator that owns facilities to generate electric power for sale to utilities and end users. The IPPs sell power to utilities under long-term feed-in tariffs or power-purchase agreements (PPAs).

Key performance indicator (KPI): a measurable value that demonstrates how effectively a company is achieving key business and operational objectives. KPIs include availability factor, forced-outage rate, etc. See Appendix E for details.

Major maintenance: planned rehabilitation interventions to perform detailed inspections and or repairs to refurbish the equipment and extend its operating life. Major maintenance costs can either be part of the OPEX or CAPEX budgets based on the accounting principles of the owner, and the magnitude of the works.

O&M management contract: an agreement between the owner and the operator to provide partial or full outsourced O&M services. O&M management services contracts are structured in a similar fashion to consulting services contracts and are usually issued on the basis of a fixed duration, lump-sum price (in terms of management fees) with milestones and deliverables (sometimes paid for separately), and performance incentives usually calculated on an annual basis.

O&M strategic-model options: include Model 1 (owner retains sole responsibility of O&M), Model 2 (partial outsourcing of O&M by the owner), and Model 3 (full outsource of O&M to an independent contractor).

O&M strategy: an informed set of high-level information and decisions toward sustainable O&M of hydropower facilities, including (i) objectives to be reached, (ii) activities and organizational decisions to reach these objectives, and (iii) adequate resources (human, financial, etc.). An O&M strategy is based on (i) a diagnosis of existing situation and stakeholders and (ii) risk assessment and targets to eliminate barriers and provide an enabling environment for success.

Operating plan: provides organization personnel with a detailed program of the tasks and responsibilities in line with the goals and objectives within the O&M strategy. It is a management tool that facilitates the coordination of the organizational resources (human, financial, and physical) so that goals and objectives in the O&M strategy can be achieved.

Operation expenditures (OPEX): covers the routine O&M costs for day-to-day facility operations and maintenance. OPEX costs are budgeted on an annual basis with a five-year forecast. OPEX are expensed in the corporate income statement.

Organizational structure: are typically hierarchical arrangements of lines of authority, communications, rights, and duties of an organization. Organizational structures determine how the roles, power, and responsibilities are assigned, controlled, and coordinated, and how information flows between the different levels of management.

Planned-interval maintenance: are carried out on a time schedule or triggered in accordance with an equipment usage schedule. This has been the traditional approach to maintenance and is included in O&M plans produced during the commissioning of projects.

Power purchase agreement (PPA): a contract between two parties: one that generates electricity (the seller) and one that looks to purchase electricity (the buyer). The PPA defines all commercial terms for the sale of electricity between the two parties, including (i) when the project will begin commercial operation, (ii) the schedule for delivery of electricity, and (iii) penalties for under delivery, payment terms, and termination. A PPA is the principal agreement that defines the revenue and credit quality of a generating facility and is thus a key instrument of project finance. There are many forms of PPA in use today and they vary according to the needs of the buyer, seller, and financing counterparties (Ross, 2018).

Predictive maintenance: makes use of condition-based monitoring of data and trending analysis to predict the likelihood and timing of potential failures. Failure prediction uses condition assessment data and test results obtained during outages as well as continuously collected monitoring data. Modern plants employ online and real-time monitoring of equipment, systems, and civil structures (movement, leakage) to provide data which are used to plan and continually fine-tune the preventative maintenance program.

Preventive maintenance: carried out at predetermined intervals or in accordance with established criteria for the purpose of reducing the probability of the failure or degradation of the function of an asset. Planned interval maintenance, condition-based maintenance, and predictive maintenance are subheadings of preventive maintenance.

Reliability-centered maintenance (RCM): a process of determining the most effective maintenance approach. The RCM philosophy employs corrective and preventive maintenance techniques (planned, condition-based, predictive) in an integrated manner to increase the probability that a machine or component will function in the required manner over its design life cycle with a minimum of maintenance. The goal of the philosophy is to provide the stated function of the facility, with the required reliability and availability at the lowest cost. RCM requires that maintenance decisions be based on maintenance requirements supported by sound technical and economic justification. To be effective, RCM requires use of real-time condition monitoring and CMMS.

Root-cause analysis (RCA): the process of drilling down to determine the actual cause of failures or poor performance. RCA goes hand in hand with RCM to improve reliability of equipment and reduce maintenance costs.

Standard operating procedures (SOPs): are a set of step-by-step instructions compiled by an organization to help workers carry out complex routine operations. SOPs aim to achieve efficiency, quality output, and uniformity of performance, while reducing miscommunication and failure to comply with regulations and or set standards. As an example, SOPs may include the operation of civil works and hydro-mechanical equipment such as spillways controlling reservoir or forebay levels within a set of reservoir operating rules. Operations may also in some cases be responsible for management of procedures related to shoreline erosion and in some cases managing the ongoing social impacts on project-affected populations, including flood and release warning systems.

Technical review: refers to hydropower engineers/maintenance staff performing condition assessments of the equipment using nondestructive testing methods (NDT) to assess the remaining life of the equipment and replacement options with original equipment design or different designs to achieve optimal results.

Work order: authorization of maintenance, repair, or operations work to be completed. Work orders can be manually generated through a work request submitted by a staff member or automatically generated through a work order management software or preventive maintenance (PM) schedule. Work orders can also be generated via follow-ups to inspections or audits.

Appendix B: Sample dashboards from technical diagnosis

TABLE B.1 | Example of output from technical diagnosis on the need for major repair/replacement

DISCIPLINE	EQUIPMENT	YEAR INSTALLED/ COMMISSIONED	STATUS (NOT FUNCTIONING)	MAJOR REPAIR/ REPLACEMENT NEEDED?	BY YEAR	DURATION STUDIES & PROCUREMENT (MONTHS)	RISKS OF ACTIONS NOT IMPLEMENTED
ELECTRICAL							
Station service	Powerhouse AC station service upgrade	1990	3	No			
Station service	Station lighting	1990	4	Yes	2020	2	Plant and staff safety
Station service	Powerhouse DC station service upgrade	1990	4	Yes	2020	4	Extended unplanned outage
Station service	Powerhouse diesel generator	1990	3	No			
Station service	Powerhouse replace battery bank (2) & chargers (4)	1990	3	No			
Station service	Powerhouse replace station service transformer	1990	1	No			
Station service	Fire detection system	1990	3	No			
Protection & controls	Protection and control upgrade (protection panels, relays, communication equipment)	1990	4	Yes	2021	7	Obsolete equipment—limited spares—extended unplanned outage
Unit 1 governor	Unit 1 governor controls upgrade	1990	5	Yes	2019	5	Extended unplanned unit outage
Unit 2 governor	Unit 2 governor controls upgrade	1990	3	No			
Substation	Replace 115 kV CBs (circuit switcher)	1990	3	No			
Substation	Replace 115 kV surge arresters	1990	3	No			
Substation	Replace 115 kV VTs & CTs	1990	3	No			
Substation	Replace GSU transformer	1990	3	No			
Substation	Install DGA monitor on GSU	1990	3	No			
MV system	4.16 kV switchgear complete with gen breaker and load break switch	1990	3	No			
MECHANICAL							
Sluice gates	LLO gate 1, hydraulic actuator and HPU	1990	3	No			
Sluice gates	LLO gate 2, hydraulic actuator and HPU	1990	3	No			
Unit 1 intake	Refurbish intake gate, hydraulic actuator and HPU	1990	3	No			
Unit 2 intake	Refurbish intake gate, hydraulic actuator and HPU	1990	3	No			
Intakes	Refurbish trashracks and cleaner	1990	3	No			
Draft tube gates	Powerhouse refurbish draft tube stoplogs and follower	1990	5	Yes	2019	2	Required for dewatering—major works
Unit 1	Refurbish cooling water systems	1990	4	Yes	2020	6	Increased maintenance costs
Unit 2	Refurbish cooling water systems	1990	4	Yes	2020	6	Increased maintenance costs
Unit 1	Refurbish unit HPU	1990	4	Yes	2020	6	Increased maintenance costs
Unit 2	Refurbish unit HPU	1990	4	Yes	2020	6	Increased maintenance costs
Unit 1	Generator rewind/stator replacement	1990	4	Yes	2020	6	Increased maintenance costs
Unit 2	Generator rewind/stator replacement	1990	4	Yes	2020	6	Increased maintenance costs
Unit 1	Rotor poles & exciter refurbishment	1990	4	Yes	2020	6	Increased maintenance costs
Unit 2	Rotor poles & exciter refurbishment	1990	4	Yes	2020	6	Increased maintenance costs
Unit 1	Turbine unit overhaul (includes runner refurb/replacement)	1990	3.5	Maybe	2022	14	Cavitation damage—extended unit outage
Unit 2	Turbine unit overhaul (includes runner refurb/replacement)	1990	3.5	Maybe	2022	14	Cavitation damage—extended unit outage
Water systems	Powerhouse refurbish service water system	1990	4	Yes	2021	3	Plant and staff safety
HVAC	Powerhouse refurbish HVAC system	1990	3	No			
Water systems	Refurbish sump pumps & oil water separator	1990	3	No			
Crane	Powerhouse OH crane refurbishment (elect & controls)	1990	5	Yes	2019	3	Urgent—required for all major repairs
CIVIL							
Access road	Regrade access road back to design	1990	5	Yes	2019	1	Urgent—safety concerns
Safety boom	Safety boom repairs/replacement	1990	5	Yes	2019	3	Urgent—safety concerns
Debris boom	Debris boom repairs/replacement	1990	5	Yes	2019	3	Urgent—safety concerns
Water conveyance	Diversion, intake and tailrace channel repairs	1990	5	Yes	2019	3	Urgent—safety concerns
Bridge	Bridge maintenance	1990	5	Yes	2019	3	Urgent—safety concerns
Main dam	Rockfill dam maintenance	1990	5	Yes	2019	3	Urgent—safety concerns
Main dam	Instrumentation monitoring	1990	5	Yes	2019	3	Urgent—safety concerns
Overflow spillway	Overflow spillway concrete repairs	1990	5	Yes	2019	3	Urgent—safety concerns
Overflow spillway	Overflow spillway channel repairs	1990	5	Yes	2019	3	Urgent—safety concerns
Low level spillway	Low level spillway concrete repairs	1990	3	No			
Low level spillway	Low level spillway concrete major rehabilitation	1990	3	No			
Low level spillway	Low level spillway equipment building repairs	1990	3	No			
Intake	Intake pier repairs	1990	3	No			
Intake	Intake deck repairs	1990	3	No			
Intake	Intake superstructure	1990	3	No			
Penstock	Penstock inspections	1990	2	No			
Penstock	Penstock repair	1990	2	No			
Powerhouse	Powerhouse substructure grouting and repairs	1990	2	No			
Powerhouse	Powerhouse superstructure repairs	1990	2	No			
Powerhouse	Powerhouse roof repairs/replacement	1990	2	No			
Powerhouse	Turbine discharge chamber concrete repair	1990	4	Yes	2021	4	Plant cleanliness—hygiene
Powerhouse	Domestic water and septic system	1990	5	Yes	2020	6	Urgent—safety concerns
Powerhouse	Tailrace pier concrete erosion repair	1990	5	Yes	2020	6	Urgent—safety concerns
Powerhouse	Tailrace deck concrete erosion repair	1990	5	Yes	2020	6	Urgent—safety concerns
Fish habitat	Fish habitat maintenance	1990	5	Yes	2020	6	Environmental compliance
General	Dam safety assessment	1990	5	Yes	2020	2	Urgent—safety concerns
General	Public safety/security	1990	5	Yes	2020	2	Public safety around dam compliance

TABLE B.2 Sample from site observations as part of diagnostic (Step 1)

NUMBER	SITE OBSERVATIONS	HPP SITE X	HPP SITE Y	HPP SITE Z
		Scale (1–5): 1-Bad 5-Good 0-Not Applicable		
1	Site orientation and job planning talk	2	3	1
2	Site & PH cleanliness	3	4	1
3	Biohazards (i.e., bird droppings)—good means no issues	4	3	2
4	General site condition	3	4	1
5	Road access	3	4	1
6	Emergency contact/emergency preparedness plan	3	3	1
7	Safety signs (PH, substation, intake, etc.)	3	3	1
8	Hazard identification	2	3	1
9	Arc flash assessment/orientation/PPE	1	1	1
10	Control room—electrical hazard presence	1	1	1
11	Staff PPE	3	3	1
12	Confined space plan/rescue/gas testing equipment	1	1	1
13	Fall arrest/working at heights	3	2	1
14	First aid cabinet/eye wash station	1	1	1
15	Oil containment system (oil drums)	2	3	1
16	Oil storage—turbine floor (fire and spill hazard)	1	1	1
17	Fire fighting equipment	3	3	2
18	Substation fencing	4	4	1
19	Substation safety—nonconductive ladders	1	1	1
20	Turbine floor—oil/water separator	3	3	1
21	Tool storage	3	3	1
22	Spare parts storage	3	3	3
23	Intake/swift water rescue	1	1	1
24	Public safety around dams	1	1	1
25	Maintenance impression	3	4	2
	Overall score	**58**	**63**	**30**
	Potential score	**125**	**125**	**125**

Appendix C: O&M job titles and summary requirements

The following tables list common job profiles mobilized for O&M activities at facility and corporate levels and identify which core jobs are often needed for small, medium, and large facilities. The tables also summarize the main tasks for each job and outline the required education and experience.

TABLE C.1 Typical hydropower O&M organization chart at the facility level

CADRE	MAIN FIELDS OF EXPERTISE	CORE FOR LARGE (L), MEDIUM (M), SMALL (S) (SEE NOTE 1)	MAIN TASK(S)	ACADEMIC EDUCATION (SEE NOTE 3)	PRACTICAL TRAINING (YEARS)	EXPERIENCE TO BE CONSIDERED QUALIFIED (YEARS)
Plant Manager	Electrical or mechanical maintenance or operations supervisor in hydropower facilities	Normally L and M (see Note 2)	Overall management responsibility and direction of core functions for the facility(s)	Degree or diploma	2–4	20
Operating Supervisor	Management of plant operations	Normally L and M (see Note 2)	Day-to-day supervision and guidance of plant operators	Degree or diploma	2	15
Mechanical Supervisor	Mechanical maintenance of hydropower plants	Normally L and M (see Note 2)	Day-to-day supervision and guidance of plant mechanical maintenance staff	Degree or diploma	4	15
Electrical Supervisor	Electrical maintenance of hydropower plants	Normally L and M (see Note 2)	Day-to-day supervision and guidance of plant electrical maintenance staff	Degree or diploma	4	15
Senior Plant Operator and Junior Plant Operator	Operation of hydropower plants	Normally L and M (see Note 2)	Day-to-day hands-on operations. (see Note 4)	Diploma	4	10—senior 6—junior
Senior Mechanical Technician, Mechanical Technician, and Mechanical Technician Trainee	Hydropower plant mechanical maintenance	All (see Note 3)	Day-to-day hand-on maintenance of mechanical equipment	Diploma	4	10—senior 8—junior
Senior Electrical Technician, Electrical Technician, and Electrical Technician Trainee	Hydropower plant electrical maintenance	All (see Note 3)	Day-to-day hands-on maintenance of electrical equipment	Diploma	4	10—senior 8—junior
Control, Protection, and Communications Technician and Technician Trainee	Digital electronics, software, firmware, protection, and control and communications equipment maintenance	All (see Note 5)	Day-to-day maintenance of control, protection, communications, and human machine interfaces	Diploma	4	10—senior 8—junior
Civil Engineer or Technologist and Trainee	Civil, geotechnical engineering, surveying, monitoring, and analysis	All (see Note 6)	Inspection and monitoring of civil structure behavior and geotechnical data collection and analysis	Degree or diploma	2–4	10—Technologist 8—Engineer
Maintenance Planner	Electrical, mechanical, operating, technical background	All (see Note 3)	RCM analysis and operation of the entire maintenance management system (see Note 7)	Technical diploma	2–4	10

CADRE	MAIN FIELDS OF EXPERTISE	CORE FOR LARGE (L), MEDIUM (M), SMALL (S) (SEE NOTE 1)	MAIN TASK(S)	ACADEMIC EDUCATION (SEE NOTE 3)	PRACTICAL TRAINING (YEARS)	EXPERIENCE TO BE CONSIDERED QUALIFIED (YEARS)
Site Administration (if applicable)	Finance, procurement, human resources generalist	L and M (see Note 8)	Day-to-day management of local finances, human resource management, and procurement and inventory management stores functions	Business diploma	3	10
General Maintenance Supervisor	General civil background in maintenance of structure, buildings, and grounds	All (see Note 3)	Day-to-day supervision and guidance of plant general labor	Civil technical diploma	Trade certification	8
General Maintenance Staff	Various backgrounds in carpentry, masonry, rigging, mobile equipment operations, and general labor	All (see Note 3)	Day-to-day general maintenance and unskilled labor support for technical staff and operation of mobile equipment, cranes, hoists, etc.	Various certifications as required by law	2–6	5

Note 1—For the purposes of this exercise, large is considered greater than an installed capacity of 250 MW. Medium is defined as 50 MW to 250 MW and small is below 50 MW.

Note 2—Facility management will differ between jurisdictions. In developed economies, small plants will likely not be staffed with any management presence, and O&M will be managed from a more centralized location if a number of facilities are involved. In developing economies, the staffing of even small hydropower plants will not vary significantly from medium-sized plants.

Note 3—The attendance at the plant of staff may vary from one organization to another depending on the plant size, location, and the potential grouping of facilities in a river cascades or water shed. Attendance would be scheduled to meet maintenance needs or to respond to problems. Small plants would not normally be staffed in developed economies but would likely be staffed in developing economies.

Note 4—Hydropower owners in developed economies are trending toward de-staffing facilities of all sizes in terms of 24/7 shift work and opting to have operators present only during normal working hours in support of maintenance staff requirements. Other owners are moving toward the elimination of the operator cadre altogether and having any required switching and clearing carried out by qualified electrical technicians. This does not currently apply to facilities in developing economies where a standard 24/7 three shift per day arrangement is still the commonplace standard. De-staffing is not possible without modern sophisticated communications and SCADA systems to support regional control centers.

Note 5—The requirement for control, protection, and communications technicians varies from owner to owner and facility to facility depending on the vintage of the equipment being employed. On the low end of expertise requirements, the maintenance functions may range from electromechanical protection relays and electrical measuring equipment to having a full working understanding of communications, SCADA, distributed control systems, and information technology in the plant environment and externally.

Note 6—The work of monitoring the behavior of civil structures is of greater interest in the early years of operation to determine the behavior of structures immediately after impoundment, so it is best if the civil staff has been involved in the construction supervision of the project structures and carry on after. But there is usually insufficient work on a day-to-day basis to justify on-site continuous presence, so these functions are usually centralized with automated data collection.

Note 7—The maintenance planning function in larger organizations is separated from the RCM analyst position, however many hydropower owners in public utilities in developing countries have not yet moved to RCM as a central part of their maintenance management.

Note 8—Site administration varies between different organizations depending on the size of the organization and the number of sites managed across the jurisdiction. Many functions such as human resource management, finance, procurement, and a variety of other administrative duties are centralized as site support services.

TABLE C.2 Typical hydropower O&M support organization chart at the corporate level

CADRE	MAIN FIELDS OF EXPERTISE	CORE FOR LARGE (L), MEDIUM (M), SMALL (S) (SEE NOTE 1)	MAIN TASK(S)	ACADEMIC EDUCATION (SEE NOTE 3)	PRACTICAL TRAINING (YEARS)	EXPERIENCE TO BE CONSIDERED QUALIFIED (YEARS)
Maintenance Engineering Department Manager	Electrical, mechanical maintenance of hydropower facilities	All	Overall management responsibility and direction of centralized engineering support for the facility sites	Degree BSc or better	4	20
Maintenance Engineering Electrical Engineer Mechanical Engineer	Electrical, mechanical maintenance of hydropower facilities	All	Support for problem solving, capital planning, and engineering for modifications or upgrades	Degree	4	15—senior 5—junior
Engineering Technologists	Electrical, mechanical maintenance of hydropower facilities	All	Support for problem solving, capital planning, and engineering for modifications or upgrades	Diploma	2	10
Maintenance Analyst (RCM) (see Note 1)	Electrical maintenance of hydropower plants	All	RCM analysis, root cause analysis, cost benefit analysis, improve procedures, and cost-effective maintenance activities	Diploma	2	10
Performance Engineer	Operation and maintenance of hydropower plants	All	Monitoring technical and financial performance indicators. Root cause analysis and designing, recommending solutions	Degree	4	15
Civil Engineering Department Manager	Hydropower plant civil structures, gates, dams and dykes, civil engineering, and geotechnical engineering	All	Overseeing the staff and programs for monitoring and inspecting civil structures, gates, water passages, and dykes, and responsible for all aspects of dam safety	Degree BSc or better	4	20
Civil Engineer Geotechnical Engineer	Hydropower plant civil structures, gates, dams and dykes, civil engineering, and geotechnical engineering	All	Monitoring, inspecting civil structures, gates, water passages, dykes, and supporting dam safety	Degree	4	15—senior 8—junior
Workplace Safety and Health Officer	Industrial safety with hydropower experience	All	Monitoring, training, investigation of accidents, liaison with corporate WPSH on hydropower specific issues	Diploma	4	15

Note 1—RCM analysis may be carried out at each site or centralized as a support service, but all maintenance program activities should be centrally scrutinized and approved for consistent application and sharing across the fleet where possible.

Appendix D: Key O&M job descriptions

The following job descriptions are described below as job profile sheets.

	POSITION
1.	Plant Manager
2.	Chief Operations Engineer
3.	Shift Supervisor
4.	Operator (plant and substation)
5.	Chief Maintenance Engineer
6.	Electrical Engineer
7.	Protection & Controls Technician
8.	Electrical Technician
9.	Substation/High Voltage Technician
10.	Mechanical Engineer
11.	Mechanical Technician
12.	Maintenance Planner and Outage Coordinator
13.	Civil Engineer
14.	Civil Technologist
15.	General Maintenance Tradesman
16.	Financial and Administration Manager
17.	Community/CSR and Public Safety Officer
18.	Environment and Social Compliance Officer
19.	Workplace Safety and Health Officer
20	Human Resources Officer
21.	Human Resources Assistant
22.	Senior Accountant
23.	Junior Accountant
24.	Procurement Officer
25.	Storekeeper
26.	Townsites (colonies) Administrator

JOB TITLE # 1	HYDROPOWER PLANT MANAGER
Reports to	Managing Director
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Plant Manager will report directly to the Managing Director and work closely with the Finance and Administration Manager and other support staff. The Plant Manager will be responsible for the safe operation and maintenance (O&M) management of the XYZ Hydroelectric Project (XYZHP). The Plant Manager will work in a team environment to manage and direct overall site operation and maintenance. The Plant Manager will strive to achieve the right balance between productivity, risk, and costs at all times to ensure the highest levels of safety and reliable energy supply at the lowest cost. In addition, the Plant Manager will be the key person to drive workplace health, safety, and operational performance culture. A strong focus on continuous improvement is also expected. The Plant Manager will be integral to the development and achievement of the strategic plan and goals of the organization.
Responsibilities and duties	■ Responsible for operation and maintenance (O&M) of XYZHP, including 24/7 O&M activities through direct reports from Chief Operation Engineer, and Chief Maintenance Engineer, which in turn direct the activities of more than [*XYZ*] field personnel; ■ Responsible for working with the management team to develop strategic business plans for the organization. Contributes to the development of departmental goals and objectives and management of the operating procedures and budgets so that the organization meets financial goals; ■ Responsible for the overall and ongoing safe and efficient operation and maintenance of the generating station; ■ Accountable for the ongoing preparation of capital and operating budgets and approving and controlling authorized expenditures; ■ Responsible for the overall performance of the generating station; ■ Ensure that the generation station meets all safety and environmental requirements, regulatory requirements, licensing requirements, and other requirements defined by the organization; ■ Produce weekly/monthly project progress reports for Managing Director, Board of Directors (BOD) and other stakeholders; ■ Participate in BOD, Steering Committee, and other meetings as directed by the Managing Director to represent the interests of the XYZ; ■ Perform other duties and responsibilities as assigned.
Qualifications and experience requirements	■ University degree in electrical, mechanical, or civil engineering. A Master in Business Administration would be an asset. Must have 20 years related to the management of hydropower assets. An equivalent combination of education and experience will also be considered; ■ Demonstrated managerial and leadership skills combined with excellent interpersonal skills and a proven track record as a team player are essential; ■ Possesses good working knowledge of plant management processes and practices and has the ability to take a leadership role in resolving related technical issues; ■ Demonstrated skills and experience in resolving complex and sensitive issues courteously and discretely, consistent with operating principles.

JOB TITLE #2	CHIEF OPERATIONS ENGINEER
Reports to	Plant Manager
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Chief Operations Engineer will report directly to the Plant Manager and work closely with the Chief Maintenance Engineer and supporting staff. The Chief Operations Engineer will be responsible for the overall operation of the XYZ Hydroelectric Project (XYZHP), and establishing all necessary operational routines and procedures, based on OEM recommendations, relevant law, and industry best practices. The Chief Operations Engineer will assist in the recruiting of shift operating staff and identifying necessary training/education for the operating staff, including a long-term staff development plan ensuring a sustainable cadre of operators.
Responsibilities and duties	■ Ensure the ongoing safe, efficient, and reliable operation of XYZHP; ■ Collaborate with Chief Maintenance Engineer in managing all scheduled station outages to maximize generating station performance; ■ Establish and maintaining procedures such as operating and emergency restoration procedures and ensure staff are fully trained in them. During times of system emergencies, must exercise independent judgment in directing restoration with respect to the safety of personnel and equipment and the requirements of the system; ■ Ensure detailed and accurate switching procedures exist for all equipment and that operating orders are accurate and properly carried out; ■ Ensure that all necessary records are maintained; ■ Ensure adherence to environmental standards within area of responsibility; ■ Implement and monitor the safety management system within the operating group; ■ May be required to assume the authority of other supervisors during their absences; ■ Recommend the selection, hiring, salary treatment, progression, termination, and discipline of subordinates; ■ Prepare and maintain shift schedules to ensure adequate staffing on each shift; ■ Prepare detailed reports of outages or disturbances in equipment under his/her jurisdiction; ■ Analyze outages and prepare recommendations to prevent a recurrence; ■ Ensure safety rules and codes of practice are followed; ■ Ensure that practices in his/her areas of responsibility comply with corporate and regulatory environmental requirements; ■ Ensure that direct reports are adequately informed and trained in environmental and regulatory requirements; ■ Participate in and/or facilitate the development of the strategic business plan; ■ Train, motivate, and direct employees to their maximum potential with regard to their well-being (job satisfaction, safety, morale, etc.); ■ Lead the team in achieving the business objectives, monitoring, and reporting on progress on an ongoing basis.
Qualifications and skills	■ University degree in electrical, mechanical, or civil engineering and 15+ years of experience related to the operations of a similar-size hydropower project. An equivalent combination of education and experience will also be considered; ■ Demonstrated commitment to safety, occupational health, and the environment is required; ■ Demonstrated managerial and leadership skills combined with excellent interpersonal skills and a proven track record as a team player are essential; ■ Possess good working knowledge of plant operations processes and practices and have the ability to take a leadership role in resolving related operational issues; ■ Demonstrated ability and experience in resolving complex and sensitive issues courteously and discretely, consistent with best operating principles.

JOB TITLE #3	OPERATIONS SHIFT SUPERVISOR
Reports to	Chief Operations Engineer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Operations Shift Supervisor will report directly to the Chief Operations Engineer and work closely with electrical and mechanical engineers and supporting staff. The Operations Shift Supervisor has responsibility for operating the XYZ Hydroelectric Project (XYZHP) in accordance with its design and OEM recommendations, relevant law and industry best practices, supervising powerhouse and substation operators, and coordinating with any maintenance work during the shift.
Responsibilities and duties	■ Supervise and perform plant inspections and complete data collection; ■ Perform the switching required to facilitate maintenance and ensure peak efficiency; ■ Communicate with control centers of three interconnected utilities and follow dispatching procedures; ■ Inform supervisory staff of any plant problems; ■ Perform restoration of power during planned and unplanned outages; ■ Assist in troubleshooting equipment; ■ Assist maintenance department in regular maintenance and inspections of the equipment; ■ Attend plant safety meetings, and follow all safety rules and regulations; ■ Responsible for lockout/tagout to isolate machinery for inspections and maintenance; ■ Issue work permits for maintenance, replacement, or repair of equipment; ■ Direct and provide on-the-job training and assist in the appraisal for junior personnel; ■ Provide emergency after-hours support (call-out) and standby duties as required.
Qualifications and skills	■ Completion of a technical diploma in electrical/mechanical engineering from an institute of recognized standing; ■ Minimum work experience of 10 years as a Supervisor in an electric utility and/or experience operating a hydropower/thermal or sophisticated industrial facility; ■ Experience using maintenance management systems; ■ Ability to organize, supervise, and schedule work and provide training, leadership, and direction to other staff; ■ Possess above average technical knowledge with a desire to further development; ■ Possess above average computer skills sufficient to perform the various tasks of the position (MS Word, MS Excel, and MS Project); ■ Possess sound judgment, decision-making ability, and the ability to perform assignments with minimum supervision; ■ Possess an excellent working knowledge of budget preparation and control, cost accounting, stores, and stock control; ■ Creative and able to evaluate and develop work methods and practices; ■ Familiar with and adhering to the corporate safety manual and other approved safety practices and procedures.

JOB TITLE #4	OPERATOR (PLANT AND SUBSTATION)
Reports to	Operations Shift Supervisor
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Operator will report directly to the Operations Shift Supervisor and work closely with substation operators and supporting staff. The Operator is responsible for operating the XYZ Hydroelectric Project (XYZHP) in peak efficiency in accordance with its design and OEM recommendations, relevant law, and industry best practices.
Responsibilities and duties	■ Perform plant inspections and complete data collection; ■ Perform the switching required to facilitate maintenance and ensure peak efficiency; ■ Communicate with control centers of three interconnected utilities and follow dispatching procedures; ■ Inform supervisory staff of any plant problems; ■ Perform restoration of power during planned and unplanned outages; ■ Assist in troubleshooting equipment; ■ Assist maintenance department in routine maintenance and inspections of the equipment; ■ Attend plant safety meetings, and follow all safety rules and regulations; ■ Participate in lockout/tagout to isolate machinery for inspections and maintenance; Issue work permits for maintenance, replacement, or repair of equipment; ■ Direct and provide on-the-job training and assist in the appraisal for junior personnel; ■ Provide emergency after-hours support (call-out) and standby duties as required.
Qualifications and skills	■ Completion of a technical diploma in electrical/mechanical engineering from an institute of recognized standing; ■ Minimum work experience of six years in an electric utility and/or experience operating a hydropower/thermal or sophisticated industrial facility; ■ Trainee—minimum work experience of two years working in an electric utility and/or experience operating a hydropower/thermal or sophisticated industrial facility; ■ Possess above average technical knowledge with a desire to further develop; ■ Possess above average computer skills sufficient to perform the various tasks of the position (MS Word, MS Excel, and MS Project); ■ Possess sound judgment, decision-making ability, and the ability to perform assignments with minimum supervision; ■ Familiar with and adhere to the corporate safety manual and other approved safety practices and procedures.

JOB TITLE #5	CHIEF MAINTENANCE ENGINEER
Reports to	Plant Manager
Job summary	As a critical member of XYZ Hydropower Company (XYZ), the Chief Maintenance Engineer will report directly to the Plant Manager and work closely with the Chief Operations Engineer and supporting staff. The Chief Maintenance Engineer will be responsible for the overall maintenance of the XYZ Hydroelectric Project (XYZHP). The Chief Maintenance Engineer will be responsible for overseeing the basic maintenance routines and procedures, based on civil contractor recommendations, relevant law, and industry best practices. The Chief Maintenance Engineer will assist in the recruiting of maintenance and engineering staff, and identifying necessary training/education for the staff, including a long-term staff development plan ensuring staff retention.
Responsibilities and duties	■ Ensure the ongoing safe, efficient, and reliable maintenance of XYZHP; ■ Collaborate with Chief Operations Engineer in managing all scheduled station outages to maximize performance; ■ Implement and monitor the safety management system within the maintenance group; ■ Institutionalize organized maintenance management processes and procedures by applying and driving facility-wide focus in identifying, planning, scheduling, and executing work; ■ Evaluate and benchmark (gap analysis) existing plant procedures/practices/performance measures versus internal and external industry-specific benchmarks; ■ Work with peers to define roles and responsibilities to ensure the success of maintenance management programs; ■ Lead maintenance improvement initiatives identified through failure root cause analysis and/or compliance, growth, or cost reduction requirements; ■ Develop detailed planning to control departmental elements, including spending, staffing, etc.; ■ Liaise with purchasing to identify and negotiate the purchase of needed components, equipment, and contract services; ■ Ensure all maintenance objectives are completed on time and within budget/forecast; ■ Assess and document success/failure of completed work orders, creating feedback to further drive effective work order execution; ■ Recommend the selection, hiring, salary treatment, progression, termination, and discipline of subordinates; ■ Ensure that practices in his/her areas of responsibility comply with corporate and regulatory environmental requirements; ■ Ensure that direct reports are adequately informed and trained in environmental and regulatory requirements.; ■ Participate in and/or facilitating the development of the strategic business plan; ■ Establish preventive and predictive maintenance tasks, including oil analysis, vibration monitoring, thermographic analysis, ultrasonic detection, sound analysis, and frequencies for crucial process and support equipment; ■ Conduct root cause failure analysis on chronic maintenance and repair issues and initiate corrective actions to equipment design and/or work practices; ■ Establish programs for and maintain mechanical, instrumentation, electrical, regulatory, and civil equipment integrity plan which aligns long-range strategic planning, turnaround activity (shutdowns), preventative maintenance activity, and predictive maintenance activity; ■ Train, motivate, and direct employees to their maximum potential with regard to their personal well-being (job satisfaction, safety, morale, etc.); ■ Lead the team in achieving the business objectives, monitoring and reporting on progress on an ongoing basis.
Qualifications and skills	■ University degree in electrical, mechanical, or civil engineering and 15+ years of experience related to the maintenance of a power plant or sophisticated industrial facility (preferably a hydropower plant). An equivalent combination of education and experience will also be considered; ■ Demonstrated commitment to safety, occupational health, and the environment is required; ■ Demonstrated managerial and leadership skills combined with excellent interpersonal skills and a proven track record as a team player are essential; ■ Possess good working knowledge of plant operations processes and practices and have the ability to take a leadership role in resolving related operational issues; ■ Demonstrated skills and experience in solving complex and sensitive matters courteously and discretely, consistent with best operating principles.

JOB TITLE #6	ELECTRICAL ENGINEER
Reports to	Chief Maintenance Engineer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Electrical Engineer will report directly to the Chief Maintenance Engineer and work closely with civil and mechanical engineers and supporting staff. The Electrical Engineer will be responsible for the overall maintenance and troubleshooting of all electrical equipment associated with the XYZ Hydroelectric Project (XYZHP). The Electrical Engineer will be responsible for establishing all necessary electrical troubleshooting, maintenance routines, and procedures, based on Civil Contractor/OE/OEM recommendations, relevant law, and industry best practices.
Responsibilities and duties	■ Supervise routine and other electrical maintenance services; ■ Provide engineering support for analyzing the electrical equipment and control problems associated with generation equipment for XYZHP; ■ Participate in the planning, scheduling, and implementation of maintenance programs for all electrical equipment and controls systems associated with XYZHP; ■ Interface with maintenance supervisors and other departments on work-related concerns and problems; ■ Assist in preparing estimates for budgetary requirements; ■ Prepare engineering reports, capital project justifications, special maintenance work order reports, and initiate purchases; ■ Investigate and evaluate equipment and parts and recommend changes to improve efficiency; ■ Update, develop, and support maintenance procedures; ■ Responsible for emergency maintenance; ■ Ensure the level of knowledge, skills, and proficiency of electrical maintenance technicians is maintained at a high standard and meet the skill requirements needed to maximize equipment operational readiness; ■ Work with Workplace Safety and Health Officer to ensure facility environmental, health, safety, and security are compliant; ■ Responsible for field testing programs and equipment commissioning as required, including the testing/commissioning of all new electrical systems; ■ Participate actively and positively in the development and achievement of the company's goals and objectives; ■ In cooperation with plant staff, develop and update maintenance standards and procedures for electrical equipment; ■ Attend plant safety meetings, and follow all safety rules and regulations; ■ Direct and provide on-the-job training and assist in the appraisal for junior personnel; ■ Provide emergency after-hours support (call-out) and standby duties as required.
Qualifications and skills	■ Graduate degree in electrical engineering from a university of recognized standing and a minimum of 15 years related experience, which includes a minimum of four years field experience directly related to the operation/maintenance or design and/or construction, commissioning of electrical equipment in hydropower generating stations including control systems; ■ Demonstrated ability to organize, schedule, and coordinate work, and to provide training to other staff; ■ Broad technical background pertaining to power equipment and auxiliaries in hydropower generating stations to carry out the duties of the position; ■ Mature judgment and the ability to carry out assigned tasks with minimal direction; ■ Ability to deal with personnel at all levels with diplomacy, inside and outside the corporation; ■ Good knowledge of engineering standards and safety standards; ■ Working knowledge of PLC/HMI systems as applied to hydro generating stations, including related troubleshooting and support processes; ■ Functional knowledge of AutoCAD, Microsoft Office, etc.

JOB TITLE #7	PROTECTION AND CONTROLS TECHNICIAN
Reports to	Electrical Engineer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Protection and Controls Technician will report directly to the Electrical Engineer and work closely with other technicians and supporting staff. The Protection and Controls Technician will be responsible for troubleshooting and maintaining protection and control equipment and SCADA systems associated with R XYZ Hydroelectric Project (XYZHP), based on OE/OEM recommendations, relevant law, and industry best practices.
Responsibilities and duties	■ Day-to-day maintenance of digital controls, protection relays, telecommunications, supervisory control and data acquisition (SCADA), and human machine interface (HMI); ■ Assist in troubleshooting problems and perform periodic inspections; ■ Investigate, analyze, and report on power quality problems, including harmonic and transient analyses, voltage profiles, etc.; ■ Perform initial inspection checks to ensure that newly installed equipment is ready to be placed in service; ■ Assist in the development of maintenance procedures and be responsible for the execution of the same; ■ Analyze HMI/SCADA and protection relays datasets for troubleshooting, regular inspections, and training purposes; ■ Attend plant safety meetings, and follow all safety rules and regulations; ■ Participate and perform lockout/tagout to isolate machinery for inspections and maintenance; ■ Direct and provide on-the-job training and assist in the appraisal for junior personnel; ■ Provide emergency after-hours support (call-out) and standby duties as required.
Qualifications and skills	■ A diploma related to electrical technology with a specialization in protection and control systems from an institute of recognized standing and or completion of training program leading to the designation of Protection and Controls Technician; ■ Minimum of eight years of experience working as a Protection and Controls Technician in a utility or in the private sector and experience with substations, generating equipment, and complex industrial systems; ■ Apprentice: Minimum of four years of experience working as a Protection and Controls Technician in a utility or private sector and experience with substations, generating equipment, and sophisticated industrial systems; ■ Must be prepared to undertake further development of technical or leadership skills through participation in internal and external training and development; ■ Thorough knowledge of the use and care of all instruments and test equipment; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions; ■ Good knowledge of station and operation, particularly modern control systems requiring high diagnostic skills and ability to read schematic drawings and blueprints; ■ Knowledge of scheduling and planning techniques, budgetary controls, functional cost accounting; ■ Ability to prepare technical reports in a clear, concise manner; ■ Conversant with and adhere to safety rules and regulations; ■ Physically capable of performing all the duties of the position.

JOB TITLE #8	ELECTRICAL TECHNICIAN
Reports to	Electrical Engineer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Electrical Technician will report directly to the Electrical Engineer and work closely with other technicians and supporting staff. The Electrical Technician will be responsible for troubleshooting and maintaining electrical equipment associated with the XYZ Hydroelectric Project (XYZHP), based on OE/OEM recommendations, relevant law, and industry best practices.
Responsibilities and duties	■ Perform troubleshooting, repair, maintenance, and acceptance tests on all medium- and low-voltage electrical equipment at the site; ■ Assist in troubleshooting problems and perform periodic inspections; ■ Assist in the development of maintenance procedures and be responsible for the execution of the same; ■ Attend plant safety meetings, and follow all safety rules and regulations; ■ Participate and perform lockout/tagout to isolate machinery for inspections and maintenance; ■ Direct and provide on-the-job training and assist in the appraisal for junior personnel; ■ Provide emergency after-hours support (call-out) and standby duties as required.
Qualifications and skills	■ A diploma in electrical technology from an institute of recognized standing and or completion of training program leading to the designation of Journeyman Electrical Technician; ■ Minimum of eight years of experience working as an Electrical Technician in a utility or in the private sector and experience with substation, generating equipment, and or complex industrial systems; ■ Apprentice: Minimum of four years of experience working as an Electrical Technician in utility or private sector and experience with substation, generating equipment, and or complex industrial systems; ■ Must be prepared to undertake further development of technical or leadership skills through participation in internal and external training and development; ■ Thorough knowledge of the use and care of all instruments and test equipment; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions; ■ Knowledge of scheduling and planning techniques, budgetary controls, functional cost accounting; ■ Ability to prepare technical reports in a clear, concise manner; ■ Conversant with and adhere to safety rules and regulations; ■ Physically capable of performing all the duties of the position.

JOB TITLE #9	SUBSTATION/HIGH VOLTAGE TECHNICIAN
Reports to	Electrical Engineer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Substation/High Voltage Technician will report directly to the Electrical Engineer and work closely with other technicians and supporting staff. The Substation/High Voltage Technician will be responsible for troubleshooting and maintaining high voltage electrical equipment associated with the XYZ Hydroelectric Project (XYZHP), based on OE/OEM recommendations, relevant law, and industry best practices.
Responsibilities and duties	■ Perform troubleshooting, repair, maintenance, and acceptance tests on high voltage equipment in XYZHP substation; ■ Assist in troubleshooting problems and perform periodic inspections; ■ Assist in the development of maintenance procedures and be responsible for the execution of the same; ■ Attend plant safety meetings, and follow all safety rules and regulations; ■ Participate and perform lockout/tagout to isolate equipment for inspections and maintenance; ■ Direct and provide on-the-job training and assist in the appraisal for junior personnel; ■ Provide emergency after-hours support (call-out) and standby duties as required.
Qualifications and skills	■ A diploma in electrical technology from an institute of recognized standing and or completion of training program leading to the designation of Journeyman High Voltage Electrical Technician; ■ Minimum of eight years of experience working as a High Voltage Electrical Technician in utility or private sector and experience with substation, generating equipment, and or complex industrial systems; ■ Apprentice: Minimum of four years of experience working as a High Voltage Electrical Technician in utility or private sector and experience with substation, generating equipment, and or complex industrial systems; ■ Must be prepared to undertake further development of technical or leadership skills through participation in internal and external training and development; ■ Thorough knowledge of the use and care of all instruments and test equipment; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions; ■ Knowledge of scheduling and planning techniques, budgetary controls, functional cost accounting; ■ Ability to prepare technical reports in a clear, concise manner; ■ Conversant with and adhere to safety rules and regulations; ■ Physically capable of performing all the duties of the position.

JOB TITLE #10	MECHANICAL ENGINEER
Reports to	Chief Maintenance Engineer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Electrical Engineer will report directly to the Chief Maintenance Engineer and work closely with Civil and Electrical Engineers and supporting staff. The Mechanical Engineer will be responsible for the overall maintenance and troubleshooting of all mechanical equipment associated with the XYZ Hydroelectric Project (XYZHP). The Mechanical Engineer will be responsible for establishing all necessary troubleshooting, maintenance routines, and procedures, based on OE/OEM recommendations, relevant law, and industry best practices.
Responsibilities and duties	■ Supervise routine and other mechanical maintenance services; ■ Provide engineering support for analyzing the mechanical equipment and control problems associated with generation equipment for XYZHP; ■ Participate in the planning, scheduling, and implementation of maintenance programs for all mechanical equipment and controls systems associated with XYZHP; ■ Interface with maintenance supervisors and other departments on work-related concerns and problems; ■ Assist in preparing estimates for budgetary requirements; ■ Prepare engineering reports, capital project justifications, special maintenance work order reports, specifications, and initiate purchases; ■ Investigate and evaluate equipment and parts and recommend changes to improve efficiency; ■ Update, develop, and support maintenance procedures; ■ Responsible for emergency maintenance; ■ Ensure the level of knowledge, skills, and proficiency of electrical maintenance technicians is maintained at a high standard and meet the skill requirements needed to maximize equipment operational readiness; ■ Work with Workplace Safety and Health Officer to ensure facility environmental, health, safety, and security are compliant; ■ Responsible for field testing programs and equipment commissioning as required, including the testing/commissioning of all new mechanical systems; ■ Participate actively and positively in the development and achievement of the company's goals and objectives; ■ In cooperation with plant staff, develop and update maintenance standards and procedures for mechanical equipment and auxiliaries; ■ Attend plant safety meetings, and follow all safety rules and regulations; ■ Direct and provide on-the-job training and assist in the appraisal for junior personnel; ■ Provide emergency after-hours support (call-out) and standby duties as required.
Qualifications and skills	■ Graduate from a mechanical engineering program from a university of recognized standing with a minimum of 15 years progressive technical experience, including four (4) years supervisory experience of engineers and technical support personnel in hydropower plants; ■ Demonstrated ability to organize, schedule, and coordinate work, and to provide training to other staff; ■ Broad professional background pertaining to power equipment and auxiliaries in hydropower generating stations to carry out the duties of the position; ■ Familiarity with Kaplan turbines and associated equipment is an asset; ■ Membership in Professional Engineering Organization; ■ Must have the ability to deal with other personnel with diplomacy in the roles of supervisor and coordinator; ■ Must be a good organizer and adept at scheduling a heavy workload; ■ Must have mature judgment and the ability to accept and complete assignments given by objective and schedule; ■ Must have a broad technical background pertaining to Mechanical Engineering; ■ Functional knowledge of AutoCAD, Microsoft Office, etc.

JOB TITLE #11	MECHANICAL TECHNICIAN
Reports to	Mechanical Engineer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Mechanical Technician will report directly to the Mechanical Engineer and work closely with other technicians and supporting staff. The Mechanical Technician will be responsible for troubleshooting, inspections, and maintenance of all mechanical equipment associated with the XYZ Hydroelectric Project (XYZHP), based on OE/OEM recommendations, relevant law, and industry best practices.
Responsibilities and duties	■ Perform troubleshooting, repair, maintenance, and inspection of all mechanical systems at XYZHP (i.e., turbine/generators, bearings, HPU, cooling water system, intake gates, spillway gates, and other balance of plant equipment, etc.); ■ Assist in troubleshooting problems and perform periodic inspections; ■ Assist in the development of maintenance procedures and be responsible for the execution of the same; ■ Attend plant safety meetings, and follow all safety rules and regulations; ■ Participate and perform lockout/tagout to isolate machinery for inspections and maintenance; ■ Direct and provide on-the-job training and assist in the appraisal for junior personnel; ■ Provide emergency after-hours support (call-out) and standby duties as required.
Qualifications and skills	■ A diploma in mechanical technology from an institute of recognized standing and or completion of training program leading to the designation of Mechanical Technician/Millwright; ■ Minimum of eight years of experience working as a Mechanical Technician in utility or private sector and experience with hydropower generating equipment, and or complex industrial systems; ■ Apprentice: Minimum of four years of experience working as a Mechanical Technician in utility or private sector and experience with hydropower generating equipment, and or complex industrial systems; ■ Familiarity with Kaplan turbines and associated equipment is an asset; ■ Must be prepared to undertake further development of technical or leadership skills through participation in internal and external training and development; ■ Thorough knowledge of the use and care of all instruments and test equipment; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions; ■ Knowledge of scheduling and planning techniques, budgetary controls, functional cost accounting; ■ Ability to prepare technical reports in a clear, concise manner; ■ Conversant with and adhere to safety rules and regulations; ■ Physically capable of performing all the duties of the position.

JOB TITLE #12	MAINTENANCE PLANNER AND OUTAGE COORDINATOR
Reports to	Chief Maintenance Engineer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Maintenance Planner and Outage Coordinator will report directly to the Chief Mechanical Engineer and work closely with Chief Electrical Engineer and supporting staff. The Maintenance Planner is responsible for the planning, scheduling outages, and the coordination of all work functions related to the maintenance management system.
Responsibilities and duties	■ Responsible for maintaining a computerized maintenance management system (CMMS) and drafting procedures and training for staff to use the system; ■ Coordinate the planning and scheduling of outages; ■ Create Gantt charts and network diagrams for unit outages; ■ Achieve close working relationships with plant management and station personnel including external crews and departments and maintain harmonious liaison with all departments concerned; ■ Plan and produce work orders and schedules for equipment requiring maintenance and provide work packages to work crews; ■ Responsible for maintaining all records in the CMMS and ensuring that all instructions, procedures, records, and files are correct and up-to-date; ■ Ensure that all completed work packages are reviewed with plant management with the intent of improving quality and efficiency of work and eliminating error; ■ Assist in preparing reports forecasting future resource requirements, equipment overhaul results, persistent problem areas, and necessary equipment modifications or replacement; ■ Assist in establishing and maintaining preventative and predictive maintenance programs consistent with RCM principles; ■ Develop and maintain various performance indicator reports for plant management; ■ Attend plant safety meetings, and follow all safety rules and regulations; ■ Direct and provide on-the-job training and assist in the appraisal for junior personnel; ■ Provide emergency after-hours support (call-out) and standby duties as required.
Qualifications and skills	■ Completion of a diploma in electrical or mechanical engineering from an institute of recognized standing; ■ Minimum work experience of 10 years working as a maintenance supervisor/planner at hydropower/thermal or complex industrial facility; ■ Possess proven maintenance experience on all major equipment and auxiliaries; ■ Experience using maintenance management systems; ■ Ability to organize, supervise, and schedule work and provide training, leadership, and direction to other staff; ■ Possess above average technical knowledge with a desire to further development; ■ Possess above average computer skills sufficient to perform the various tasks of the position (MS Word, MS Excel, and MS Project); ■ Possess sound judgment, decision-making ability, and the ability to perform assignments with minimum supervision; ■ Possess an excellent working knowledge of budget preparation and control, cost accounting, stores, and stock control; ■ Creative and able to evaluate and develop work methods and practices; ■ Familiar with and adhere to the corporate safety manual and other approved safety practices and procedures.

JOB TITLE #13	CIVIL ENGINEER
Reports to	Chief Maintenance Engineer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Civil Engineer will report directly to the Chief Maintenance Engineer and work closely with Electrical and Mechanical Engineers and other support staff. The Civil Engineer is responsible for civil works related to the XYZ Hydroelectric Project (XYZHP) and their operation and maintenance based on its design parameters, OEM/OE recommendations, relevant law, and industry best practices.
Responsibilities and duties	■ Conduct inspections of all civil works according to schedule and oversee the surveillance and monitoring program to maintain dam safety; ■ Manage the timely review, and any necessary follow-up action as required, of all surveillance and monitoring datasets to assure the safety of project civil works; ■ Provide technical support to the townsite administrator on any road or building issues, as well as slope stability; ■ Provide technical oversight on hydrology/hydraulic analysis and any changes in floodplain mapping and studies; ■ Review and approve of any modification to XYZHP dam or appurtenant facilities which might impact their safety; ■ Direct changes to project operations if necessary, to ensure the safety of XYZHP dam, spillway, and appurtenant facilities during emergency circumstances; ■ Review and approval of emergency actions plans; ■ Participate in dam safety inspection by regulatory authorities; ■ Participate in the planning, scheduling, and implementation of maintenance programs for all civil works associated with the generating stations; Interface with other maintenance supervision and other departments or work-related concerns and problems; ■ Assist in preparing estimates for budgetary requirements; ■ Prepare Engineering Reports, Capital Project Justifications, Special Maintenance Work Order Reports, specifications, and initiate purchases; ■ Update, develop, and recommend maintenance procedures; ■ Work with Workplace Safety and Health Officer to ensure facility environmental, health, safety, and security are compliant; ■ Participate actively and positively in the development and achievement of the team's goals; ■ Direct and provide on-the-job training and assist in the appraisal for junior personnel; ■ Provide emergency after-hours support (call-out) and standby duties as required.
Qualifications and skills	■ University degree in civil engineering and a minimum of eight years of experience related to the design, construction, and operation of access roads, dams, tunnels, and hydropower plant. An equivalent combination of education and experience will also be considered; ■ Demonstrated commitment to occupational health and safety; ■ Demonstrated managerial and leadership skills combined with excellent interpersonal skills and a proven track record as a team player are essential; ■ Possess good working knowledge of plant operations processes and practices and have the ability to take a leadership role in resolving related operational issues; ■ Demonstrated skills and experience in solving complex and sensitive matters courteously and discretely, consistent with best operating principles.

JOB TITLE #14	CIVIL TECHNOLOGIST
Reports to	Civil Engineer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Civil Technologist will report directly to the Civil Engineer and work closely with other technicians and supporting staff. The Civil Technologist will be responsible for inspection and monitoring of civil structures, and geotechnical data collection and analysis related to the XYZ Hydroelectric Project (XYZHP) based on Civil Contractor and Owner's Engineer recommendations, relevant law, and industry best practices.
Responsibilities and duties	■ Inspect and maintain all civil works (dam, intake, powerhouse, etc.) associated with XYZ Hydroelectric Project (XYZHP); ■ Download and analyze dam safety instrument datasets and any other geotechnical dataset on-site; ■ Maintain and update project GIS database including site surveys, maps, and drawings; ■ Operate and maintain a variety of mechanical, digital, analogue, wireless, computerized, and other equipment required for engineering surveys; ■ Attend project safety meetings, and follow all safety rules and regulations; ■ Assist in the development of maintenance procedures and be responsible for the execution of the same; ■ Direct and provide on-the-job training and assist in the appraisal for junior personnel; ■ Provide emergency after-hours support (call-out) and standby duties as required.
Qualifications and skills	■ Diploma in civil engineering technology from an institute of recognized standing; ■ Minimum experience of 10 years in utility or private sector and experience with design, construction, or operation of hydropower projects or other major civil infrastructure; ■ Prepared to undertake further development of technical or leadership skills through participation in internal and external training and development; ■ Knowledge of scheduling and planning techniques, budgetary controls, functional cost accounting; ■ Ability to prepare technical reports in a clear, concise manner; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions; ■ Conversant with and adhere to safety rules and regulations; ■ Physically capable of performing all the duties of the position.

JOB TITLE #15	GENERAL MAINTENANCE TRADESMAN
Reports to	Civil Engineer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the General Maintenance Tradesman will report directly to the Civil Engineer and work closely with other technicians and supporting staff. The General Maintenance Tradesman will be responsible for the day-to-day supervision and guidance of general plant labor in performing maintenance of civil structures related to the XYZ Hydroelectric Project (XYZHP) based on Civil Contractor and OE recommendations, relevant law, and industry best practices.
Responsibilities and duties	■ Supervise and guide general labor in performing maintenance works at all civil structures, buildings, and grounds associated with XYZ Hydroelectric Project (XYZHP); ■ Attend project safety meetings, and follow all safety rules and regulations; ■ Assist in the development of maintenance procedures and be responsible for the execution of the same; ■ Direct and provide on-the-job training and assist in the appraisal for junior personnel; ■ Provide emergency after-hours support (call-out) and standby duties as required.
Qualifications and skills	■ Diploma in civil engineering technology from an institute of recognized standing; ■ A minimum experience of eight years in utility or private sector and experience with construction supervision of hydropower projects or other major civil infrastructure; ■ Prepared to undertake further development of technical or leadership skills through participation in internal and external training and development; ■ Knowledge of scheduling and planning techniques, budgetary controls, functional cost accounting; ■ Ability to prepare technical reports in a clear, concise manner; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions; ■ Conversant with and adhere to safety rules and regulations; ■ Physically capable of performing all the duties of the position.

JOB TITLE #16	FINANCIAL AND ADMINISTRATION MANAGER
Reports to	Managing Director
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Finance and Administration Manager will report directly to the Managing Director and work closely with the Plant Manager and other support staff. The Finance and Administration Manager will be responsible for the finance and administration functions of the XYZ Hydroelectric Project (XYZHP).
Responsibilities and duties	■ Manage finance and procurement functions of XYZHP; ■ Manage tariff justification and approvals, payment collection from utilities, and loan repayments and all financial matters of XYZHP; ■ Manage townsite administration; ■ Manage community relations, environmental and social compliance, and workplace health and safety functions of XYZHP; ■ Manage human resources team supporting XYZHP; ■ Provide management with financial advisory support services including the interpretation of financial results, operating and capital cost budget preparation, and reporting; ■ Responsible for working with the management team to develop strategic business plans for the organization. Contributes to the development of departmental goals and objectives and management of the operating procedures and budgets so that the organization meets financial goals; ■ Manage capital and operating budgets, approving and controlling authorized expenditures; ■ Produce weekly/monthly project progress reports for Managing Director, BOD, and other stakeholders; ■ Participate in BOD, Steering Committee, and other meetings as directed by the Managing Director to represent the interests of the XYZ; ■ Perform other duties and responsibilities as assigned.
Qualifications and experience requirements	■ University degree in finance, accounting, and/or business administration. A Master's degree in Business Administration would be an asset; ■ Must have 15 years related to the management of finance and admin departments of a utility and/or a small to medium public/private institution. An equivalent combination of education and experience will also be considered; ■ Demonstrated managerial and leadership skills combined with excellent interpersonal skills and a proven track record as a team player are essential; ■ The successful candidate will also demonstrate proficiency in all of the corporate leadership and core competencies with particular emphasis on: visionary leadership, developing competency in others, building customer relations, building trust, communication, and financial responsibility.

JOB TITLE #17	COMMUNITY/CSR AND PUBLIC SAFETY OFFICER
Reports to	Financial and Administration Manager
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Community/CSR and Public Safety Officer will report directly to the Finance and Administration Manager and work closely with the Plant Manager and other support staff. The Community/CSR and Public Safety Officer will be responsible for managing the public and community relationships with all stakeholders in countries UV and W. He/she will also maintain the corporate social responsibility (CSR) function, and workplace health and safety function of the XYZ Hydroelectric Project (XYZHP).
Responsibilities and duties	■ Supervise environmental and social compliance officer; ■ Supervise workplace safety and health officer; ■ Implement CSR action items and manage stakeholder relationships and public safety related to the operation of XYZHP; ■ Manage budget related to CSR, stakeholder management, environmental and social compliance, and workplace health and safety; ■ Produce weekly/monthly project progress reports for manager; ■ Assist the manager with other internal and external communications as required, including news releases, executive speeches, event planning, articles, brochures, and reports; ■ Ensure all communications support corporate goals and objectives; ■ Serve as a corporate spokesperson on media inquiries as directed by manager; ■ Perform other duties and responsibilities as assigned.
Qualifications and experience requirements	■ University degree in business administration, communications, and or public affairs from an institute of recognized standing; ■ Must have 15 years of related experience in communication, public affair departments of a utility, and/or a large public/private institution. An equivalent combination of education and experience will also be considered; ■ Demonstrated supervisory and leadership skills combined with excellent interpersonal skills and a proven track record as a team player are essential.

JOB TITLE #18	ENVIRONMENT AND SOCIAL COMPLIANCE OFFICER
Reports to	Community/CSR and Public Safety Officer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Environmental and Social Compliance Officer will report directly to the Community/CSR and Public Safety Officer and work closely with Operation and Maintenance staff of the XYZ Hydroelectric Project (XYZHP). The Environmental and Social Compliance Officer will be responsible for monitoring compliance with environmental and social impact mitigation programs during the operation phase of the project.
Responsibilities and duties	■ Monitor environmental and social impact mitigation plans during the operation phase of the XYZHP as outlined in ESIA and project permits and authorizations; ■ Coordinate and compile regulatory compliance reports; ■ Coordinate and implement internal inspection programs; ■ Coordinate with operations and assist in resolving deficiencies identified by various inspections; ■ Assist in monitoring samples tracking and reporting; ■ Implement programs to ensure environmental and social compliance including drafting plans and reports, and compiling and analyzing data relating to compliance and process quality control work; ■ Manage contractors and consultants, as needed; ■ Work with Workplace Safety and Health Officer to ensure facility environmental, health, safety, and security are compliant; ■ Attend plant safety meetings, and follow all safety rules and regulations; ■ Direct and provide on-the-job training and assist in the appraisal for junior personnel.
Qualifications and experience requirements	■ University Degree in business management, chemistry, environmental sciences, or related field from an institute of recognized standing; ■ Must have 10+ years of relevant experience in environmental and social impact assessments, and/or compliance experience of civil and power infrastructure. An equivalent combination of education and experience will also be considered; ■ Must be prepared to undertake further development of technical or leadership skills through participation in internal and external training and development; ■ Ability to prepare compliance reports in a clear, concise manner; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions; ■ Conversant with and adhere to safety rules and regulations; ■ Physically capable of performing all the duties of the position.

JOB TITLE #19	WORKPLACE SAFETY AND HEALTH OFFICER
Reports to	Community/CSR and Public Safety Officer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Workplace Safety and Health Officer will report directly to the Community/CSR and Public Safety Officer and work closely with Operation and Maintenance staff of the XYZ Hydroelectric Project (XYZHP).
Responsibilities and duties	■ Apply knowledge of current and upcoming health and safety strategies, procedures, regulations, and industry best practices; ■ Develop and coordinate health and safety systems/strategies meeting and exceeding organizational and compliance requirements; ■ Align with management to address health and safety issues and drive implementation of new initiatives; ■ Conduct field audits to monitor employees on safe work practices; ■ Hands-on supervision of all field staff journey management requests; ■ Track and audit organizational performance and compliance against policies, programs, and procedures; ■ Advise and represent the company during regulatory actions; ■ Review and develop work and site plans, which supports a safe workplace environment; ■ Attend necessary operations meetings to discuss health and safety concerns and issues; ■ Participate in health and safety committee meetings; ■ Develop and conduct monthly safety meetings on topics designed to promote a better understanding of company policies, programs, procedures, and general health and safety; ■ Respond in a timely fashion to the incident; lead completing all incident investigations; ■ Track and oversee regular reporting of health and safety metrics to develop KPIs to drive the business toward exceeding organizational compliance goals; ■ Work with operations group to ensure safe work procedures are developed and appropriate for all field operations; ■ Other duties as required.
Qualifications and experience requirements	■ Diploma in safety and/or environmental management or related field from an institute of recognized standing; ■ Must have 10+ years as a safety officer in a utility environment with hands-on working experience in a safety management system (SMS); ■ Valid standard First Aid and CPR certifications and other safety training such as Fall Arrest, Confined Space, etc.; ■ Ability to work collaboratively as part of a cohesive team, as well as the ability to work independently with minimal supervision; ■ Flexibility regarding scheduling (open to working nights or days for auditing); ■ Must be able to adapt to changes in a work environment, travel, and weather; ■ Conversant with and adhere to safety rules and regulations; ■ Physically capable of performing all the duties of the position.

JOB TITLE #20	HUMAN RESOURCES OFFICER
Reports to	Finance and Administration Manager
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Human Resources Officer will report directly to the Finance and Administration Manager and work closely with the Plant Manager, Chief Operation Engineer, and Chief Maintenance Engineer of the XYZ Hydroelectric Project (XYZHP). The Human Resources Officer plays a key role in the recruitment and retention of staff from the three partner countries and both public and private sector.
Responsibilities and duties	■ Communicate and work with managers throughout all phases of recruiting, including development and updating of existing job descriptions; determining recruiting strategies, interviewing, and selection; drafting offer letters; communication of selection decisions to candidates; ■ Participate in annual reviews, individual performance plans, tracking due dates for performance evaluations, and follow up with supervisors and managers; ■ Assist management with employee learning and development activities, including training and capacity building; ■ Assist management with issues related to pay grades, raises, benefits, and compensation; ■ Recommend new approaches, policies, and procedures to effect continual improvements in the efficiency of the department and services performed; ■ Manage leaves of absence and return to work programs; ■ KPI reporting related to human resources; ■ Direct and provide on-the-job training and assist in the appraisal for junior staff; ■ Other duties as assigned.
Qualifications and experience requirements	■ University degree/diploma in human resources or related field from an institute of recognized standing; ■ Must have 10+ years of relevant experience of managing Human Resources Department of a utility, public and/or private institution; ■ Must know local and regional labor laws; ■ Must be prepared to undertake further development of business or leadership skills through participation in internal and external training and development; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions; ■ Must have a thorough understanding and working knowledge of local industry employment norms and compensation, including employment benefits.

JOB TITLE #21	HUMAN RESOURCES ASSISTANT
Reports to	Human Resources Officer
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Human Resources Assistant will report directly to the Human Resources Officer and work closely with the support staff of the XYZ Hydroelectric Project (XYZHP).
Responsibilities and duties	■ Work with Human Resources Officer in the design, development, analysis, and testing of HR reports, reporting software, and organizational management strategies; ■ Maintain, problem solve, remedy issues, and provide technical support for existing computer applications developed for human resources administration; ■ Responsible for delivering biweekly, monthly, quarterly, semiannual, and annual HR reports for management; ■ Assist management with the formulation and implementation of standardized job descriptions, performance management, hiring, discipline, and termination of employees; ■ Assist management with employee learning and development activities, including training and capacity building; ■ Assist management with issues related to pay grades, raises, benefits, and compensation; ■ Maintain organizational management business process procedure documents; ■ Assist with the development and delivery of HR IT system user training; ■ Work closely with staff from various departments; ■ Attend training sessions as required; ■ Other duties as assigned.
Qualifications and experience requirements	■ Diploma in human resources or related field from an institute of recognized standing; ■ Must have 5+ years of relevant experience of working in human resources at a utility, public and/or private institution; ■ Must know local and regional labor laws; ■ Must be prepared to undertake further development of business or leadership skills through participation in internal and external training and development; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions.

JOB TITLE #22	SENIOR ACCOUNTANT
Reports to	Finance and Administration Manager
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Senior Accountant will report directly to the Finance and Administration Manager and work closely with the Plant Manager, Chief Operation Engineer, and Chief Maintenance Engineer of the XYZ Hydroelectric Project (XYZHP).
Responsibilities and duties	■ Oversee the efficient and reliable operation of the Accounting Department; ■ Coordinate budget and finance activities between the various operation, maintenance, and administration departments of XYZ; ■ Responsible for payroll administration of XYZ staff; ■ Responsible for the monthly, quarterly, and year-end reporting of OM&A expenditures, including the preparation of company annual and quarterly reports, corporate management report, year-over-year analysis, and year-end working papers; ■ Responsible for the monthly, quarterly, and year-end reporting of capital expenditures, including summarization of project-variance analysis; ■ Assist in the coordination and rollup of the corporation's annual OM&A budget submission; ■ Provide functional and technical guidance and professional advice on finance and accounting matters through financial analysis, interpretation of results, the recommendation for changes and improvements involving use and control of local financial resources; ■ Coordinate customer inquiries, payment of arrears, disconnection issues, etc.; ■ Manage the preparation of operating and administrative expense reports on a monthly, quarterly, and yearly basis to compare actual costs with approved budget and forecast; ■ Prepare the consolidated equivalent full-time employee report and provide analysis for the monthly management report; ■ Provide assistance to finance staff with financial system reporting queries; ■ Attend training sessions as required; ■ Other duties as assigned.
Qualifications and experience requirements	■ University degree in accounting, business administration, and/or related field from an institute of recognized standing; ■ Completion of a recognized professional accounting designation; ■ Must have 15+ years of relevant experience as a controller, senior accountant in an SME public or private institution; ■ Must have complete working knowledge of international accounting rules and best practices; ■ Must be prepared to undertake further development of business or leadership skills through participation in internal and external training and development; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions.

JOB TITLE #23	JUNIOR ACCOUNTANT
Reports to	Senior Accountant
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Junior Accountant will report directly to the Senior Accountant and work closely with the support staff of the XYZ Hydroelectric Project (XYZHP).
Responsibilities and duties	■ Perform general accounting duties (i.e., data entry and filing); ■ Responsible for accounting reconciliation works, month-end closing, accounting reports, and accounting analysis, etc.; ■ Ensure all reporting is accurate and processes are completed by the stipulated deadlines; ■ Prepare profit and loss performance and management reports; ■ Assist in preparation of budgets and implementation of new projects; ■ Preparation and filing of corporate taxes; ■ Provide assistance to finance staff with financial system reporting queries; ■ Attend training sessions as required; ■ Other duties as assigned.
Qualifications and experience requirements	■ University degree/diploma in business administration/accounting and or related field from an institute of recognized standing; ■ Completion of a recognized professional accounting designation; ■ Must have 5+ years of related experience as an accountant in large public and or private institution; ■ Must know local and international accounting rules and best practices; ■ Must be prepared to undertake further development of business or leadership skills through participation in internal and external training and development; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions.

JOB TITLE #24	PROCUREMENT OFFICER
Reports to	Senior Accountant
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Procurement Officer will report directly to the Senior Accountant and work closely with the Plant Manager, Chief Operation Engineer, and Chief Maintenance Engineer of the XYZ Hydroelectric Project (XYZHP).
Responsibilities and duties	■ Provide research, administrative, and technical support to staff on the procurement of goods and services to ensure accuracy, timeliness of information, and compliance with governing legislation, policies, and procedures; ■ Provide support in preparation, processing, and maintenance of procurement instruments and contracts in accordance with internal controls and relevant public sector procurement legislation. Conduct initial needs assessment and determination relating to the use of tenders, RFP, RFQ, local purchase orders, etc.; ■ Coordinate, participate, and/or process various procurement activities including bid openings, change orders, security deposits, progress payments, contracts, etc.; ■ Assist with the administration of annual service and supply contracts; ■ Develop and maintain supplier relationships; ■ Maintain the computerized procurement system; ■ Liaise with suppliers and staff on matters relating to procurement, internal controls, and relevant legislation; ■ Coordinate delivery schedules, monitor progress, and liaise with clients and suppliers to resolve issues; ■ Coordinate asset disposals from a financial perspective; ■ Provide input and maintain relevant policies and procedures including contract administration manual and procurement templates; ■ Maintain electronic and manual procurement records; ■ Other related duties.
Qualifications and experience requirements	■ University degree/diploma in business administration and/or related field from an institute of recognized standing; ■ Completion of a recognized procurement designation; ■ Must have 10+ years of related experience as a procurement officer in large public and or private institution; ■ Must be prepared to undertake further development of business or leadership skills through participation in internal and external training and development; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions.

JOB TITLE #25	STOREKEEPER
Reports to	Senior Accountant
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Storekeeper will report directly to the Senior Accountant and work closely with the support staff of the XYZ Hydroelectric Project (XYZHP).
Responsibilities and duties	■ Perform the key duties of warehousing; ■ Track corporate materials inventory, provide reports, and ensure reports are accurate and up to date; ■ Assist with the ordering and purchase of materials to ensure stock levels remain at proper levels, and the procurement of services as required; ■ Research material sourcing options and prepare reports for management; ■ Ensure all materials ordered abide by specifications laid out by each respective ordering department; ■ Conduct inventory and warehouse maintenance activities (including counting and sampling) regularly as required; ■ Track all orders and invoices, and maintain accurate records; ■ Attend training sessions as needed; ■ Other duties as assigned.
Qualifications and experience requirements	■ Diploma in business administration/accounting and/or related field from an institute of recognized standing; ■ Must have five years of related experience as an accountant/storekeeper in large public and/or private institution; ■ Thorough knowledge of principles, techniques, and procedures of supply chain management; ■ Good understanding of accounting/materials management software; ■ Must be prepared to undertake further development of business or leadership skills through participation in internal and external training and development; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions.

JOB TITLE #26	TOWNSITES ADMINISTRATOR
Reports to	Senior Accountant
Job summary	As a key member of XYZ Hydropower Company (XYZ), the Townsites Administrator will report directly to the Finance and Administration Manager and work closely with the management of the XYZ Hydroelectric Project (XYZHP).
Responsibilities and duties	■ Responsible for property management services for corporate housing and facilities; ■ Responsible for contracted services such as security force, canteen operations, guesthouse operations, clinic operations, water and wastewater management, garbage collection, building maintenance, residential maintenance, and roads and access; ■ Prepare annual budget and work with accounting staff to track costs and prepare monthly reports for the management; ■ Responsible for the monthly, quarterly, and year-end reporting of capital expenditures including summarization of project variance analysis; ■ Attend training sessions as required; ■ Other duties as assigned.
Qualifications and experience requirements	■ University degree/diploma in business administration and/or related field from an institute of recognized standing; ■ Must have 10+ years of related experience as a property manager/supervisor in large public and or private institution; ■ Must be prepared to undertake further development of business or leadership skills through participation in internal and external training and development; ■ Possess initiative and mature judgment with the ability to make and implement sound decisions.

Appendix E: Performance measurement: Key performance indicators

Within the electrical utility industry, hundreds of performance measures have been formulated, and comparisons of these measurements have been carried out. As detailed in Step 1, the reason for measurements and comparisons is to determine if actual performance is achieving the targets set in the O&M strategy and is comparable with others in the industry.

The comparison of actual performance with internally established targets aims to identify and guide the actions that will help the corporation meet its overall objectives. The comparison with others is to identify best performers within the industry, to understand best practices, and subsequently learn from these high performers in order to improve a utility's own overall performance.

Performance measurement and internal comparisons

Most electrical utilities develop performance measures that help them in developing (and guiding) the actions required to ensure that the utility meets the goals and objectives set out in its annual corporate strategic plan (business plan). In practice, the goals and objectives are developed first, then the measures and corresponding targets are established, and then the comparisons of actual performance versus target performance is made. In order to ensure that a company's business plan does not become too focused on one or two "performance areas" (e.g., finance and reliability), a number of goals and objectives are identified across the performance spectrum, and hence, the key performance indicators (KPIs) are also created to monitor the performance across this spectrum.

The most common performance areas that many utilities focus on are safety, financial, plant (unit), environmental impact, and human resources.

Within these performance areas, commonly used KPIs are as shown in Table E.1.

Performance measurement and external comparisons (benchmarking) for hydropower

If performance measurement comparisons are to be made with other utility companies, also known as "benchmarking," it is imperative that the comparisons are made with similar utilities/plants and that the data are collected and analyzed in a similar fashion. There is no use in comparing the performance of two dissimilar utilities or comparing data that were not collected in the same fashion. It is important that KPI data (performance measurement information) are collected and shared in an open and consistent manner.

Several associations exist that encourage benchmarking and, as such, they provide their members with the measurement and analysis guidelines (or standards) required to ensure that comparisons are meaningful and consistent. These associations allow members to:

- benchmark their performance data (KPI) against other member utilities
- learn from "best in class" organizations
- share successes and failures
- collectively solve problems
- strive for continuous improvements.

TABLE E.1 Commonly used key performance indicators

PERFORMANCE AREA	KPI
Safety performance	■ Number of lost time injuries (also known as accident frequency rate) ■ Number of person days lost due to injuries (also known as accident severity rate) ■ Number of high-risk incidents ■ Other "leading" indicators: ❑ Percentage of "work site" visits performed by crew supervisors ❑ Staff participation in safety meetings/safety training program ❑ Implementation of accident investigation recommendation
Financial performance	■ Cost of O&M/O&M budget (expressed as a percentage) ■ Cost of capital expenditures/capital budget (expressed as a percentage) ■ Cost of special maintenance work orders/maintenance work order budget (expressed as a percentage)
Plant (unit) performance	■ Plant availability factor ■ Unit forced outage rate ■ Other "leading" indicators: ❑ Emergency work/total work (expressed as a percentage) ❑ Maintenance work completed/maintenance work planned (expressed as a percentage) ❑ Percentage of outages investigated (root cause analysis performed) ❑ Percentage implementation of outage investigation recommendations
Environmental impact performance	■ Number of releases of environmentally damaging products (oil, sulfur hexafluoride, etc.) ■ Number of dam safety violations ■ Number of domestic water and sewage treatment noncompliance occurrences ■ Other "leading" indicators: ❑ Accidental releases of harmful products from its primary storage vessel ❑ Percentage staff trained in emergency response ❑ Percentage of staff trained in dam safety ❑ Percentage staff that have reviewed the spill response manual (annually)
Employee skills and relations	■ Percentage of staff that have a personal development plan ■ Percentage of performance reviews completed ■ Percentage of staff that have met the development plan objectives ■ Employee survey staff satisfaction index

Examples of North American associations include the Electrical Utilities Cost Group (EUCG Inc.), the Canadian Electricity Association (CEA), and the National Hydropower Association (NHA).

The EUCG Inc. (formerly known as the Electric Utility Cost Group) is an international association of utility professionals that shares information with the goal of increasing their performance and competitiveness. The international membership is devoted to promoting accuracy, quality, and efficient data management, and because of this dedication, the EUCG is able to provide state-of-the-art plant performance data to its members. The EUCG hosts a semiannual conference and workshop program that is attended by approximately 110 representatives of the world's major international utility companies. Networking between members at these events allows for the sharing of reliable information exchange and best practices.

Within the EUCG Inc., a committee has been established to provide the standard in the hydroelectric industry for "energy performance information." This committee is known as the Hydroelectric Productivity Committee (HCP).

Benchmarking KPIs are primarily grouped into three groups. Although there are many KPIs within each of these three groups, there are two in each that are of prime importance, as detailed in Table E.2.

To ensure that valid performance indicator comparisons can be made between utilities, the EUCG's Hydro Electric Productivity Committee has produced very detailed definitions for the various data inputs. These definitions are contained in the User Guide and Data Catalog, available to EUCG members.

TABLE E.2 | Two key indicators on performance, costs, and staffing

CATEGORY	INDICATORS	DESCRIPTION
Performance group	Availability factor (AF): indicator of how well the utility has managed the maintenance program to keep the units (station) in a sound operating mode.	The availability factor (expressed as a percentage) is calculated as follows: AF = (available hours/reporting period hours) × 100 *where* available hours are a sum of: ■ Service hours (hours where the unit is connected to the grid) ■ Reserve shutdown hours (unit is available, but shutdown for economic reasons) ■ Pumping hours (if applicable—the hours that the turbine/generator is operated as a pump/motor) ■ Condensing hours (if applicable—the hours that the generator is run as a synchronous condenser)
	Forced outage rate (FOR): indicator of the health of the equipment	Forced outage rate (expressed as a percentage) is calculated as follows: FOR = (forced outage hours/forced outage hours + service hours) × 100 *where* Forced outage hours is a sum of all hours that a unit was off-line due to immediate, delayed, and postponed forced outages. By definition, a forced outage is an outage caused by an unplanned component failure or other condition that requires that a unit be removed from service immediately or before the next weekend. Service hours is a sum of all hours where the unit is connected to the grid.
Costs group	Production cost per unit: indication of the total production costs associated with generating a MWh of electricity for a given reporting period.	It is expressed as: Operating costs + maintenance costs/total electricity generated (in MWh) Operating costs are cost items, activities, or services which directly impact or control the operation of the plant/facility or involve the management of the system as a whole with the specific outcome being the generation of electrical energy. Power Marketing (trading) activities are not included. Maintenance costs are cost activities specifically directed at supporting or ensuring that equipment or facilities are available when required, to support the operation of the plant/facility.
	Production cost per installed capacity: indication of the total production costs associated with the total installed capacity to generate electricity for a given reporting period.	It is expressed as: Operating costs + maintenance costs/total installed capacity (in MW) Operating costs are cost items, activities, or services which directly impact or control the operation of the plant/facility or involve the management of the system as a whole with the specific outcome being the generation of electrical energy. Power marketing (trading) activities are not included. Maintenance costs are cost activities specifically directed at supporting or ensuring that equipment or facilities are available when required to the support operation of the plant/facility.

(continued)

TABLE E.2 Continued

CATEGORY	INDICATORS	DESCRIPTION
Staffing group	Full time equivalent (FTE) per unit: indication of the total number of staff associated with generating a MWh of electricity for a given reporting period.	It is expressed as: Number of full time equivalent staff/total electricity generated (in MWh). Full time equivalents = all regular hours + all overtime hours/hours per FTE. *Where* Regular hours are all normal working hours (non-overtime) worked at the plant site in the operations, maintenance, or support functions of the plant. Overtime hours are all nonregular working hours worked at the plant site in the operations, maintenance, or support functions of the plant. Hours per FTE are the number of hours worked by a permanent plant employee working regular paid hours.
	Full time equivalent (FTE) per installed capacity: indication of the total number of staff associated with the total installed electrical generating capacity for a given reporting period.	It is expressed as: Number of full time equivalent staff/total installed capacity (in MW) Full time equivalents = all regular hours + all overtime hours/hours per FTE *Where* Regular hours are all normal working hours (non-overtime) worked at the plant site in the operations, maintenance, or support functions of the plant. Overtime hours are all nonregular working hours worked at the plant site in the operations, maintenance, or support functions of the plant. Hours per FTE are the number of hours worked by a permanent plant employee working regular paid hours.

Canadian Electricity Association (CEA): Canadian utilities make annual data submissions to several groups within the CEA organization. The first one is the Committee on Corporate Performance and Productivity Evaluation (COPE) that established over 227 KPIs to allow for comparisons of performance in the following areas:

- 24 corporate overall KPIs
- 66 customer service KPIs
- 45 distribution KPIs
- 28 transmission KPIs
- 19 corporate service KPIs
- 45 power supply KPIs

The second CEA group to which utilities submit data is the Consultative Committee on Outage Statistics (CCOS) which reports annually on their equipment reliability information system (ERIS). This committee identifies the top 10 performers in terms of generating unit level performance. The ERIS data submittal entails reporting every state change the generating unit makes within a given period, and the KPIs are calculated from that information. No power generation is reported to this system.

The state changes reported are:

- available states
    - operating (O)
    - operating under forced derating (OFD)
    - operating under scheduled derating (OSD)

- available but not operating (ABNO)
- available but not operating forced derating (ABNO-SD)
- available but not operating scheduled derating (ABNO-SD)

- not available states
  - forced outage (FO)
  - forced extension of maintenance outage (FEMO)
  - forced extension of planned outage (FEPO)
  - maintenance outage (MO)
  - planned outage (PO)

The ERIS KPIs are then reported in terms of:

- incapability factor (ICbF)—the ratio of total equivalent outage time, in hours to number of unit hours
- de-rated adjusted forced outage rate (DAFOR)—the ratio of equivalent forced outage time to equivalent force outage time plus total equivalent operating time
- available but not operating factor (ABNOF)—calculated by dividing ABNO + ABNO-FD + ABNO-SD by unit hours.

Note: For further reference, see:

- EUCG website: www.eucg.org
- CEA website: www.canelect.ca
- NHA website: www.hydro.org

Appendix F: Template terms of reference for soliciting preparation of an O&M strategy

This template is to be adapted by owner according to local context and needs. Items between *[in italic]* will need in particular to be customized. Terms of references will be also adapted depending whether the O&M strategy targets an existing hydropower fleet or a greenfield project.

Terms of Reference
Preparing an Operation and Maintenance Strategy for *[name of the hydropower power plant or name of the utility, country]*

1. Background and context

Hydropower is the largest renewable source, accounting for two-thirds of the world's renewable generation. In order to optimize the available hydropower capacity, efficient operation and effective maintenance practices are critical. While safeguarding the environment and the safety of employees and surrounding communities, hydropower plants maximize stakeholder benefits. Operation and maintenance (O&M) refers to all activities needed to run a hydropower plant, project or fleet (excluding replacement or construction of new facilities, but generally can include rehabilitation of existing components, and maintenance overhauls).

While new dams are being commissioned and new hydropower plants will be constructed, major challenges in hydropower O&M are faced by operators and utility managers. Poor O&M results in significant tangible consequences, including loss of electricity production, loss of revenues, high outage rates, performance losses and, in time, heavy rehabilitation/replacement costs, which are often much higher than preventive O&M costs. More indirect and longer-term impact of poor O&M also includes threats to dam, public, and environmental safety which may even lead to emergency situations, and eventually loss of lives and properties. This is not only due to a lack of technical capacity of utilities, but also due to a shortage of financial resources of the utilities to operate the plants.

[Brief description of:

- *country context,*
- *hydropower fleet targeted by this consultancy, its status and O&M difficulties encountered,*
- *key stakeholders, including the client . . .]*

In that context, *[the client]* seeks the support of a consultant to prepare an O&M strategy which will sustain the efficiency of its hydropower fleet over the long run. The proposed O&M strategy should cover the full life cycle of the fleet from commissioning through operations and multiple life extensions/rehabilitation programs to the end at decommissioning, dismantling, or reconstruction, while providing more details for the upcoming [5–15] years to come.

2. Objectives of the consultancy

The consultant shall assist *[the client]* to prepare, validate, and get approved an ad-hoc O&M strategy for its hydropower fleet.

The O&M strategy will, among others, aim to:

- reduce downtime and improve plant and equipment availability
- increase power production
- improve public, staff, and plant safety
- improve legal, regulatory, environmental, and social compliance
- prolong asset life
- *[to be completed].*

The objectives of the services will be achieved through the following major activities:

- diagnosis of O&M performance over the last *[X]* years
- design of the O&M strategy (objectives and activities)
- estimation of human and financial resources
- support during validation and approval process
- design of a detailed roadmap to implement the new strategy *[including a five-year CAPEX plan and next year operating plan].*

3. Scope of work

In order to meet these objectives, the consultant shall carry out the following set of activities:

- **Step 1: Diagnosing existing O&M performance.** The consultant will (i) determine how well the existing operator has been operating as well as (ii) assess its O&M capacity, procedures, and organization *[or for a greenfield: assess the O&M capacity of the foreseen operator].* Through indicators to be proposed by the consultant, the consultant will also assess the following: safety performance, financial performance, plant (unit) performance, environmental impact performance, and employees' skills, knowledge, and relations. The diagnostic should at least assess the following **key performance indicators (KPIs):** availability factor (AF), forced outage rate (FOR), accident frequency rate, accident severity rate, number of releases of environmentally damaging products (oil, sulfur hexafluoride, R22, etc.). In this first step, the consultant will (i) gather and analyze all data available and deemed necessary for the diagnosis, (ii) implement on-site visits for visual inspections (not outages and/or equipment disassembling are foreseen at this stage), and (iii) implement interviews with key management and technical staff (on-site but also at corporate/utility level).

  On this basis, the consultant will prepare **a condition assessment** of most critical components of the fleet to understand the nature and scope of any works required to restore, secure, and/or modernize the facility. The consultant will then investigate/analyze whether the identified needs are reasonable given the age and operating hours of the facilities or brought about mainly because of inadequate O&M practices; and if so, what were the root causes **(root cause analysis).** The consultant will also assess whether the need for rehabilitation may also arise due to site conditions, a fault in the original design, or inadequate quality or construction methods.

  The consultant will also implement a **diagnosis of O&M capabilities, organization, and practices** of both the owner and the operator. *[For developers of new projects, this will entail examination of the experience and capabilities of the foreseen operator.]* The consultant will, among others, implement an operational review of the following items at corporate and plants' levels:

- the operator's O&M procedures and knowledge
- the operator's organization structure and roles and responsibilities
- the operator organization's governance structure
- the experience, qualifications, and training of staff
- the organization's retention and recruitment processes
- the confidence in and efficiency of the management body
- regulatory settings and impacts (rules, contractual obligations, restrictions, performance requirements, reporting, existence of independent regulatory/controlling institutions, etc.)
- comparison of expenditures against allocated budget and of the work executed with what was planned
- sufficiency of funds allocated to the O&M program.

On this basis, the consultant will prepare a **risk assessment** in order to prioritize items/equipment/resources/organizational and capacity features that deserve special attention. In preparing such risk assessment, the consultant will assess each of the main scheme components (or functional system) for its likelihood and consequence of failure, or impact (on safety but also revenues). Based on the combination of the likelihood and impact, the risk's criticality level will be classified. This risk assessment will also help in prioritizing strategic activities and where needed requirements for repair and refurbishment. The consultant is required to detail proposed methodology for such risk assessment in his proposal.

Where improvements are required, the consultant will propose and prioritize changes to be made to eliminate the root causes of poor performance, including if needed, changes in the business environment, financing resources for O&M . . . as well as in tariffs and/or government subsidies when revenues are insufficient to cover costs.

As a synthesis of this step, the consultant will produce **a diagnosis report** that, if deemed necessary, will include recommendations for activities/further measures/equipment that would support improving data collection and associated diagnosis. At this stage, the consultant will confirm KPIs that will drive the strategy.

- **Step 2: Defining objectives for the O&M strategy.** Based on the diagnosis, the consultant will articulate and quantify O&M objectives to be reached by the strategy. *[At this stage, the client emphasizes the importance of X/Y aspects but requires the consultant to review these priorities].* The proposed objectives should highly contribute to the overall business and performance objectives of the utility. Proposed objectives should also be consistent with state-of-the-art technical operating rules, legal and regulatory requirements, establishing modern maintenance management systems to preserve and prolong the life of the assets, ensuring the safety of assets and people, while protecting the environment. At this stage, the consultant will synthetize, quantify, and value expected marginal technical and financial benefits from the proposed objectives (in comparison with a business-as-usual scenario).

- **Step 3: Identification of activities to build the O&M strategy.** Based on the diagnosis and objectives targeted, the consultant will hereby identify and propose activities that will seek to substantially reduce major risks and eliminate barriers to efficiency as identified in the root cause analysis. At this stage, the consultant will in particular confirm recommendations for overall (and/or for each functional system) type of maintenance to be unrolled (preventive versus corrective, planned interval, condition-based, or predictive . . .). Consider their importance in terms of costs, the consultant will (i) review the need for maintenance of major equipment/components, (ii) recommend associated strategy (repair, refurbishment, or replacement), and (iii) assess associated costs. This will be translated into a [5–15] years CAPEX/major maintenance plan including high-level assessment for combining some activities toward optimization of procurement and costs and minimizing planned outage periods (and associated revenues losses). The consultant will also explore relevance and need for: *[list to be screened/completed considering local specificities and priorities]* modernization, upgrading, repurposing part of the fleet, improving procedures and quality standards, installation of and training in a computerized maintenance management system (CMMS), opportunities for expanding peaking capacity and/or ancillary services, development of hydro-connected or floating solar . . . The consultant will also provide advice on supporting actions, agreements, and special provisions required to ensure that an enabling business environment is created for the O&M strategy to succeed.

  The consultant will then assess (i) existing capacity to implement all recommended activities and (ii) potential need for external/outsourced support.

- **Step 4: Selection of the most adequate O&M contractual model.** Based on the activities selected in Step 3 and capability assessed in the diagnosis (such as owner's capabilities, availability of local human resources, current business and political environment . . .), the consultant will explore O&M contractual models to distribute activities between internal implementation and/or external supports/contracts. Different types of O&M contractual models considered could be based under the following broad categories (that the consultant can customize and further detail as per local ad-hoc needs):

  - Model 1: The owner retains sole responsibility for O&M.
  - Model 2: The owner outsources some O&M responsibilities to consultants, contractors, or suppliers.
  - Model 3: The owner outsources all O&M responsibility to an independent operator.

  The consultant will detail potential needs for external support, ranging from capacity building and training activities, technical assistances, service contracts, performance-based management contracts . . . [If deemed necessary, option for affermage or concession arrangements may have to be considered.] The consultant will also draft key terms of the proposed contracts, including distribution of risks and responsibilities between parties, time and lump sum based components, bonuses and penalties, description of KPIs (including metrics) to measure performance. On this basis, the consultant will summarize all activities and contracts to be implemented, including recommendation for procurement methods, estimated costs of contracts, and timelines. The consultant will also recommend allocation of responsibility for implementing and procuring these activities in a responsibility matrix (such as those illustrated in the following reference: https://en.wikipedia.org/wiki/Responsibility_assignment_matrix).

- **Step 5: Organization and staffing options.** In light of activities and contractual arrangements proposed in Steps 3 and 4, the consultant will complement the gap analysis initiated in Step 1 in order to compare current available staff and skills with those required to implement the O&M strategy. The consultant will recommend balanced and ad-hoc organization and staffing arrangements including O&M corporate and on-site organograms, positions and functions required, potential adjustments to existing staffing, guidance on recruitment timing, and need for training. The consultant will also deliver job descriptions (including education and qualification requirements) for all key (existing and/or new) staff.

  The consultant will also propose recommendations for enhancing careers' management and human resources incentives to be developed for motivating staff to perform and value their skills over time within the company. In case of major outsourcing of activities, the consultant will also propose arrangements that maximize on-the-job training for internal resources and when relevant, that could potentially enable internalization/transfer of staff by the operator at the end of outsources contracts.

- **Step 6: Estimation of financial resources.** The consultant will estimate the main OPEX and CAPEX expenditures required to implement the recommended O&M strategy. The consultant will also plan and estimate the overall required O&M budget over a five-year horizon and projected longer-term major maintenance work, and for major capital replacements and refurbishment projects within [10–15 years]. By doing so, the consultant should make sure that a sufficient budget will be planned so that the facilities can be operated and maintained in accordance with targeted objectives and good industry practice.

- **Step 7: Validation of the strategy.** The consultant will carry out cost-benefit analysis (including some sensitivity analysis) to validate the financial viability of the O&M strategy. On this basis, if needed, the consultant will provide adjustment to objectives targeted in Step 2, activities recommended in Step 3, and associated cost until forecasted financially sustainability is achieved. The cost-benefit analysis should incorporate direct and indirect costs and revenues, including energy losses during outages. Need and costing for insurances will also be evaluated.

  The consultant will also organize internal (and where needed external) stakeholder consultations *[broad list to be provided by the client]* on the basis of which the consultant will suggest options to adjust the strategy.

- **Step 8: Preparation of roadmap to implement the strategy.** The consultant will prepare a detailed roadmap to support the client in implementing the strategy. In close collaboration with the O&M management team, the consultant will also prepare the next five-year capital program and next year annual operating plan that will frame next year activities and kick-off O&M improvements. The consultant will also provide guidance on monitoring and performance measurement to ensure the effectiveness of the strategy implemented.

  The utility management will be closely involved by the consultant at every step of the process. As an iterative process, all activities mentioned above will always be conducted in close coordination with ministerial counterparts *[to be listed].*

[The client may add here any requirements for the consultant to support actual implementation of the strategy or any other foreseen tasks such as dam safety for example.]

4. Deliverables and outputs

Duration of services is [7] months after contract is signed (t0) *[duration to be adjusted depending on the size of the fleet included in the strategy]*.

The consultant is expected to submit the following deliverables within:

#	LABEL	CONTENT	TIMELINE
A	Inception report	Update of the methodology and workplan. Data collected.	t0 + 1 month
B	Step 1 and 2 report: Diagnosis and objectives	1. Detailed diagnostic with quantitative and qualitative assessment of the plant (or the fleet) performance and operator's capabilities. 2. Strategic objectives needed to ensure sustainable O&M of the facility.	t0 + 2 months
C	Step 3 and 4 report: Activities and contractual arrangements	The report will include review of all options/activities and contractual arrangements explored and comparative discussions on the pros and cons of different options.	t0 + 3 months
D	Step 5, 6, and 7 report: HR arrangements and cost-benefit estimate	Cf. scope of work for details. Including stakeholders' consultation.	t0 + 4 months
E	O&M strategy	Key outcomes from all steps—self-standing document.	t0 + 5 months
F	Step 8: Implementation plans	Detailed roadmap to support the client in implementing the strategy + next five-year capital program + next year annual operating plan.	t0 + 6 months

Final versions of reports will be submitted no later than two weeks after reception of comments. The client is committed to deliver comments no later than two weeks after reception of draft reports.

The consultant will also organize two workshops: one for presenting key outputs from deliverables B and C and another one with deliverable D.

The consultant will also be required to put in place an on-line shared database that will gather all information collected. The database will be handed over to the client at the end of the assignment.

5. Qualification requirements

The consultant should have implemented at least one similar contract in the last *[10]* years. The consultant should have skills at least in hydropower operation and maintenance, electro-mechanical engineering, asset management, business planning, and financial analysis. The consultant should have strong interpersonal and communication skills to be able to interact with the utility and plant staff at all levels.

Proposed key staff shall meet the qualifications and requirements listed in the following table. In addition, all staff must be fluent in *[English]* (written and oral), and well versed in the use of standard computer tools such as the Microsoft Office Suite. The consultant is invited to list in his proposal (i) adjustments to proposed key staff where deemed relevant and (ii) any other non-key specialists. Where relevant, a single CV could be submitted for different positions.

The person who will be designated as Team Leader must also have excellent skills in project management as well as excellent oral and written communication skills. Knowledge of *[language]* is not compulsory but would be an asset.

[Titles and requirements can be adjusted depending on local features and expectations from the client.]

TITLE	YEARS OF EXPERIENCE	SPECIFIC EXPERTISE
O&M Specialist *[team leader]*	12	At least seven years of experience in O&M of hydropower fleet, including at least five years in management. Preference for a generalist having integrated views between technical, financial, managerial, human-resources, HSE, etc., aspects. Experience in understanding and managing corporate and governance issues linked to O&M will be preferred.
Electromechanical Engineer	10	Engineer with at least seven years of experience in O&M of electro-mechanical equipment. Technical knowledge in key hydropower equipment including turbine, gates, valves, penstocks, etc.
Control and Protection/SCADA Specialist	10	Electrical Engineer or technician involved as key staff for the design (and if possible O&M) of control and protection and SCADA systems for at least three HPP projects.
Human-Resources, Capacity-Building Specialist	10	Professional with at least 10 years of experience in the development of human resources. The proposed candidate must be familiar with the requirements in the energy sector, and preferably the electricity sector with hydropower content. He/she must have previous experience in at least two projects where skills gap analyses were carried out and shall demonstrate the successful implementation of the recommended program. Proven track record of working with local staff in developing countries is essential. Knowledge of *[country/area]* conditions is considered an asset.
Financial Analyst	7	Experience in power generation from various sources, including in at least two hydroelectric projects in Africa. Good knowledge of international and regional environmental and social policies and WB environmental and social framework as they relate to hydro developments, as well as legal framework and property/land issues in Liberia and the region.

***[Other staff that can be considered as key or non-key:** Hydromechanical engineer; cost estimator; electrical engineer (switchyard and transmission); civil engineer; health, environment, and social experts]*

The consultant is requested to present in his proposal key resumes, proposed methodology, as well as level of efforts required for each step.

6. Reporting and institutional arrangements

The consultant will work under direct guidance/supervision of *[add function]*.

The methodology of implementing services should be a part of the consultant proposal.

A steering committee chaired by *[either the plant or utility manager]* will meet at the end of every step to share the results and validate the deliverables. A project committee gathering *[a smaller group of people—functions required to be listed]* will meet with the consultant to assess the project progress.

7. Client inputs

[client name] will provide to the consultant all necessary project documentations and support the consultant in collecting data and arranging necessary meetings. *[client name]* will also arrange the work place in *[location]*.

[For further guidance on methodology and outputs under each step, the consultant may consult the handbook developed by the World Bank and available online.]

Appendix G: Template for OPEX costs (with illustrative data)

A	HEAD OFFICE AND ADMINISTRATION						TOTALS
A1	Labor	Staff/shift	No. of shifts*	No. of staff	All-in rate[1]	Annual cost	
		no.	no.	no.	USD pa	USD pa	
	General manager	1	1	1	75,000	75,000	
	Personnel manager	1	1	1	50,000	50,000	
	Accountant	1	1	1	40,000	40,000	
	Administration assistant	1	1	1	20,000	20,000	
	Secretary	2	1	2	15,000	30,000	
	Driver	2	1	2	15,000	30,000	
	Laborer		1	0		0	
	Security guard	1	4	4	10,000	40,000	
	Subtotal labor			**12**		**285,000**	**285,000**

**Note:* For 3 shift operation allow additional shift for leave/rotation.

[1]Labor rates to include for leave, social costs, employer's pension contributions, and other staff-related costs.

A2	Administrative expenses	Units	Rate	Quantity	Annual cost	Subtotals	
			USD per unit		USD pa	USD pa	
	Utilities	per month	1,000	12	12,000		
	Telecommunications and post	per month	800	12	9,600		
	Travel and accommodation	per month	1,500	12	18,000		
	Subscriptions	per month	150	12	1,800		
	Printing and stationery	per month	250	12	3,000		
	Entertainment	per month	250	12	3,000		
	Amortization of office equipment	per annum	5,000	1	5,000		
	Amortization of furniture	per annum	5,000	1	5,000		
	Advertising	per month	250	12	3,000		
	Sundry expenses	per annum	1,000	1	1,000		
	Office maintenance	per month	250	12	3,000		
	Subtotal				**64,400**	**64,400**	
A3	**Fees and facility related costs**						
	Office insurance	per annum	3,000	1	3,000		
	Rates	per annum	10,000	1	10,000		
	Corporate insurances	per annum	150,000	1	150,000		
	Generation license	per annum	50,000	1	50,000		
	Office service charge	per month	200	12	2,400		
	Business registration	per annum	500	1	500		
	Interest and bank charges	per annum	1,000	1	1,000		
	Subtotal				**216,900**	**216,900**	
A4	**Vehicles, tools, and equipment**						
	Amortization of 4 × 4	per annum	10,000	1	10,000		
	Amortization of car	per annum	6,000	1	6,000		
	Maintenance 4 × 4	per annum	5,000	1	5,000		
	Maintenance car	per annum	2,500	1	2,500		
	Road tax 4WD	per annum	500	1	500		
	Road tax car	per annum	250	1	250		
	Insurance 4WD	per annum	1,000	1	1,000		
	Insurance car	per annum	500	1	500		
	Subtotal				**25,750**	**25,750**	

A5	Fuel and consumables	Units	Rate	Quantity	Annual cost	Subtotals	
	Fuel for vehicles	per month	1,000	12	12,000		
	Office consumables	per month	500	12	6,000		
	Subtotal				**18,000**	**18,000**	
A6	**External services**						
	Auditors	per annum	20,000	1	20,000		
	Cleaners	per month	200	12	2,400		
	Training	per annum	3,000	1	3,000		
	Legal services	per annum	20,000	1	20,000		
	Consultancy services	per annum	20,000	1	20,000		
	Software licenses	per annum	10,000	1	10,000		
	Recruitment services	per annum	10,000	1	10,000		
	Subtotal				**85,400**	**85,400**	
	TOTAL expenses					**410,450**	**410,450**
	Total head office and administration OPEX						**695,450**

B	POWERSTATION AND OPERATIONS						TOTALS
B1	**Labor**	**Staff/shift**	**No. of shifts***	**No. of staff**	**All-in rate[1]**	**Annual cost**	
		no.	no.	no.	USD pa	USD pa	
	Plant manager	1	1	1	60,000	60,000	
	Chief operation engineer	1	1	1	50,000	50,000	
	Shift supervision	1	4	4	40,000	160,000	
	Shift operator	2	4	8	30,000	240,000	
	Chief maintenance engineer	1	1	1	50,000	50,000	
	Mechanical engineer	1	1	1	40,000	40,000	
	Electrical engineer	1	1	1	40,000	40,000	
	Control and protection engineer	1	1	1	40,000	40,000	
	Civil engineer	1	1	1	40,000	40,000	
	Technicians	8	1	8	20,000	160,000	
	Safety officer	1	1	1	30,000	30,000	
	Environment & social compliance officer	1	1	1	30,000	30,000	
	Human resources manager	1	1	1	40,000	40,000	
	Workshop manager	1	1	1	30,000	30,000	
	Workshop mechanic	3	1	3	20,000	60,000	
	Store manager	1	1	1	30,000	30,000	
	Secretary	2	1	2	15,000	30,000	
	Laborer	10	1	10	15,000	150,000	
	Cleaner	4	1	4	10,000	40,000	
	Driver	5	1	5	15,000	75,000	
	Security guard	5	4	20	10,000	200,000	
	Subtotal labor			**76**		**1,595,000**	**1,595,000**

**Note:* For 3 shift operation allow additional shift for leave/rotation.

[1]Labor rates to include for leave, social costs, employer's pension contributions, and other staff-related costs.

B2	Administrative expenses	Units	Rate	Quantity	Annual cost	Subtotals	
			USD per unit		USD pa	USD pa	
	Utilities	per month	2,500	12	30,000		
	Telecommunications and post	per month	500	12	6,000		
	Travel and accommodation	per month	2,000	12	24,000		
	Printing and stationery	per month	100	12	1,200		
	Entertainment	per month	200	12	2,400		
	Amortization of office equipment	per annum	10,000	1	10,000		
	Amortization of furniture	per annum	10,000	1	10,000		
	Sundry expenses	per annum	5,000	1	5,000		
	Subtotal				**88,600**	**88,600**	
B3	**Fees and facility related costs**						
	Rates	per annum	100,000	1	100,000		
	Wayleaves and rents	per annum	75,000	1	75,000		
	Royalties	per annum	50,000	1	50,000		
	Subtotal				**225,000**	**225,000**	
B4	**Vehicles, tools, and equipment**						
	Amortization of 4 × 4	per annum	10,000	6	60,000		
	Amortization of bus/truck	per annum	6,000	4	24,000		
	Maintenance 4 × 4	per annum	5,000	6	30,000		
	Maintenance bus/truck	per annum	2,500	4	10,000		
	Road tax 4WD	per annum	500	6	3,000		
	Road tax bus/truck	per annum	250	4	1,000		
	Insurance 4WD	per annum	1,000	6	6,000		
	Insurance bus/truck	per annum	500	4	2,000		
	Amortization of maintenance tools	per annum	50,000	1	50,000		
	Amortization of strategic spares	per annum	100,000	1	100,000		
	Subtotal				**286,000**	**286,000**	
B5	**Fuel and consumables**						
	Fuel for vehicles	per month	5,000	12	60,000		
	Office consumables	per month	500	12	6,000		
	Lubricants	per month	2,000	12	24,000		
	Consumable spare parts	per month	5,000	12	60,000		
	Subtotal				**150,000**	**150,000**	
B6	**External services**						
	Consultancy services	per annum	100,000	1	100,000		
	Training	per annum	15,000	1	15,000		
	Software licenses	per annum	25,000	1	25,000		
	Subtotal				**140,000**	**140,000**	
	Total expenses					**889,600**	**889,600**
	Total powerstation OPEX						**2,484,600**

C	CAMP, CANTEEN AND MEDICAL FACILITIES						TOTALS
C1	Labor	Staff/shift	No. of shifts*	No. of staff	All-in rate[1]	Annual cost	
		no.	no.	no.	USD pa	USD pa	
	Camp administrator	1	1	1	50,000	50,000	
	Camp maintenance engineer	1	1	1	35,000	35,000	
	Laborer	6	1	6	15,000	90,000	
	Security guard	4	4	16	10,000	160,000	
	Canteen manager	1	1	1	40,000	40,000	
	Cook	2	1	2	25,000	50,000	
	Canteen assistant	2	1	2	15,000	30,000	
	Doctor	1	1	1	40,000	40,000	
	Nurse	3	1	3	20,000	60,000	
	Ambulance driver	1	1	1	15,000	15,000	
	Driver	1	1	1	10,000	10,000	
	Subtotal labor			**35**		**580,000**	**580,000**

**Note:* For 3 shift operation allow additional shift for leave/rotation.
[1]Labor rates to include for leave, social costs, employer's pension contributions, and other staff-related costs.

C2	Administrative expenses	Units	Rate	Quantity	Annual cost	Subtotals	
			USD per unit		USD pa	USD pa	
	Sundry expenses	per annum	5,000	1	5,000		
	Building maintenance	per month	5,000	12	60,000		
	Subtotal				**65,000**	**65,000**	
C3	**Fees and facility related costs**						
	Insurances	per annum	2,000	1	2,000		
	Rates	per annum	5,000	1	5,000		
	Subtotal				**7,000**	**7,000**	
C4	**Vehicles, tools, and equipment**						
	Amortization of 4 × 4	per annum	10,000	1	10,000		
	Amortization of ambulance/truck	per annum	6,000	2	12,000		
	Maintenance 4 × 4	per annum	5,000	1	5,000		
	Maintenance ambulance/truck	per annum	2,500	2	5,000		
	Road tax 4WD	per annum	500	1	500		
	Road tax ambulance/truck	per annum	250	2	500		
	Insurance 4WD	per annum	1,000	1	1,000		
	Insurance ambulance/truck	per annum	500	2	1,000		
	Amortization of canteen equipment	per annum	5,000	1	5,000		
	Amortization of maintenance tools	per annum	50,000	1	50,000		
	Amortization of medical equipment	per annum	20,000	1	20,000		
	Subtotal				**110,000**	**110,000**	

C5	Fuel and consumables	Units	Rate	Quantity	Annual cost	Subtotals	
	Fuel for vehicles	per month	2,000	12	24,000		
	Food and supplies	per month	10,000	12	120,000		
	Medical supplies	per month	1,000	12	12,000		
	Consumable spare parts	per month	1,000	12	12,000		
	Subtotal				**168,000**	**168,000**	
C6	**External services**						
	Training	per annum	2,000	1	2,000		
	Subtotal				**2,000**	**2,000**	
	Total expenses					**352,000**	**352,000**
	Total camp, canteen and medical facilities OPEX						**932,000**
	Total labor costs						**2,460,000**
	Total expenses						**1,652,050**
	Total facility OPEX						**4,112,050**

Appendix H: Detailed case studies

Six case studies illustrate the steps detailed in the report. They cover a range of types and sizes of facilities and show the practical application of the models described in Step 4. Detailed description of the case studies can be found in a companion report titled *Operation and Maintenance Strategies for Hydropower—Six Case Studies*.

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