Private Sector Hydropower Development Project

Manual for Developing and Reviewing Water Quality Monitoring Plans and Results for Hydropower Projects

Department of Electricity Development, HMG Nepal, in Collaboration with United States Agency for International Development and International Resources Group

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Manuals in this series:

Manual for Preparing Scoping Document for Environmental Impact Assessment (EIA) of Hydropower Projects.
Manual for Preparing Terms of Reference (TOR) for Environmental Impact Assessment (EIA) of Hydropower Projects, with Notes on EIA Report Preparation.
Manual for Preparing Environmental Management Plan (EMP) for Hydropower Projects.
Manual for Reviewing Scoping Document, Terms of Reference (TOR) and Environmental Impact Assessment (EIA) Reports for Hydropower Projects.
Manual for Preparing Initial Environmental Examination (IEE) Report for Hydropower Projects.
Manual for Public Involvement in the Environmental Impact Assessment (EIA) Process of Hydropower Projects.
Manual for Developing and Reviewing Water Quality Monitoring Plans and Results for Hydropower Projects.
Manual for Prediction, Rating, Ranking and Determination of Significant Impacts in Environmental Impact Assessment (EIA) of Hydropower Projects.

FOREWORD

Environmental Impact Assessment (EIA) is one of the proven tools of facilitation to achieve the goal of environmentally and socially sound and sustainable development. The incorporation of EIA in hydropower projects in Nepal was initiated in the early eighties. However, with the enforcement of the Environment Protection Act (EPA) and the Environment Protection Rules (EPR) in 1997, the integration of EIA in hydropower projects has now become compulsory. Large-scale hydropower projects were gaining attention for the integration of EIA prior to the enforcement of EPR. But, they were all initiatives from the donor agencies. At present, we have our own national system of EIA. A large number of proposed and on-going hydropower projects have already completed an EIA study. Some of them have been approved by the government agencies and are in the process of implementation. However, in the course of gaining experience about the processes and procedures of EIA implementation, we have become aware that the process needs to be improved.

In March 2000, the Department of Electricity Development (DOED), the National Environmental Impact Assessment Association of Nepal, International Resources Group (IRG), and the US Agency for International Development organized a one-day interagency workshop. The objective of this event was to carry out a SWOT analysis of the EIA process for hydropower projects in Nepal. A major conclusion of the participants was that the EIA process could be improved and streamlined by producing a series of manuals that would clarify the requirements at each stage in the process. Thus, the DOED, in collaboration with IRG, has developed sectoral manuals for improving the EIA process for hydropower projects. The draft manuals produced under this program are then being refined through a series of interagency workshops.

A workshop to finalize the *Manual for Developing and Reviewing Water Quality Monitoring Plans and Results for Hydropower Projects* was conducted at the School for Environmental Management and Sustainable Development (SchEMS) on 16 March 2001. A total of 23 participants consisted of senior representatives from the DOED, The Ministry of Water Resources (MOWR), the Ministry of Science and Technology, the Water and Energy Commission Secretariat, the Department of Hydrology and Meteorology, the Water Engineering and Training Centre (P.) Ltd., Nepal Electricity Authority, Lamjung Electricity Development Company, IRG, METCON Consultants, and SchEMS. This publication is the result of the dedicated effort of the participants.

I sincerely hope that these manuals will be useful to streamline the present practice of EIA relevant to hydropower projects in Nepal. I am confident that these manuals will considerably improve the current practices of EIA in Nepal, making the system more beneficial, meaningful, and efficient for achieving environmentally and socially sound and sustainable hydropower development in Nepal.

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Table of Contents

1. INTRODUCTION

The Department of Electricity Development (DOED), within the Ministry of Water Resources MOWR), is developing a set of manuals for preparing and reviewing an Environmental Impact Assessment (EIA) specifically directed to hydropower projects in Nepal. These manuals are being prepared by the DOED with the cooperation of international consultants led by the International Resources Group, Ltd. (IRG) and funded by the US Agency for International Development (USAID) Private Sector Hydropower Development Project (PSHDP). The purpose of the PSHDP is to assist in developing a licensing process for hydropower development, specifically directed to projects to be developed by private investor groups. The manuals are designed to provide developers with an understanding of how they can meet the environmental, social, engineering, and financial requirements of His Majesty's Government of Nepal (HMGN). The initial set of manuals focus on developing and reviewing the Scoping Document that serves as a basis for developing the Terms of Reference (TOR) or study plan for the EIA. A component of the EIA includes the development of an Environmental Monitoring and Management Plan (EMP) that specifies environmental mitigation measures to be incorporated into a hydropower development and the monitoring plans that will be conducted during construction and operation of the project to evaluate the performance of the hydropower project relative to environmental concerns.

Given the framework for conducting an EIA of hydropower as defined in the general manuals described above, additional sets of manuals are needed to address specific environmental aspects that are to be discussed in the EIA and are a basis for evaluating the performance of the project once it becomes operational. The first set of these technical manuals addresses the development of study plans, monitoring plans and review of those plans for evaluating the impacts of a hydropower development on water quality. Water quality was selected as the topic for the first of the technical manuals because changes to water quality will affect both the biological integrity of the river and the suitability of the water for human use.

This manual is designed to provide an outline for preparing and reviewing plans to monitor water quality during the pre-construction phase (baseline studies), construction period, and operational period. To understand the effects of hydropower projects on water quality, a brief discussion of some of the more important effects attributable to hydropower developments are discussed and possible mitigation measures suggested. This is followed by describing a minimum set of water quality parameters that should be included in the water quality monitoring plans for assessing the effects of hydropower developments. The following section provides guidelines for preparing effective and meaningful water quality monitoring programs to be conducted during each phase of the project cycle. To meet the EIA requirements of Nepal, the developer is responsible for preparing and implementing water quality monitoring programs to determine baseline conditions (contained in the TOR) and to evaluate the effects attributable to construction and operation of the hydropower project (contained in the EIA). The final section provides questions to assist in the review and approval of the respective monitoring plans and review of the results.

1.1. Hydropower Project Effects

Numerous effects of hydropower projects have been documented. Generally these can be classified into three orders of impacts (from M.P. McCartney, C. Sullivan and M.C. Acreman, 1999):

i. **First order impacts** - these are the immediate abiotic and biotic effects that occur simultaneously with dam closure and influence the transfer of energy, and material, into and within the downstream river and connected ecosystems (e.g. changes in flow, water quality and sediment load).

ii. **Second order impacts** - these are the changes of channel and downstream ecosystem structure and primary production, which result from the modification of first order impacts by local conditions and depend upon the characteristics of the river prior to dam closure (e.g. changes in channel and floodplain morphology, changes in plankton, macrophytes and periphyton). These changes may take place over many years.

iii. **Third order impacts** - these are the long-term, biotic, changes resulting from the integrated effect of all the first and second order changes, including the impact on species close to the top of the food chain (e.g. changes in invertebrate communities and fish, birds and mammals). Complex interactions may take place over many years before a new "ecological equilibrium" is achieved.

Second and third order impacts, as defined above, result from the primary or first order impacts attributable to dam construction and operation, that is, that the changes that are directly caused by the dam and its operating regime result in or cause changes in the components that are dependent upon those primary factors. The two main first order impacts of hydropower developments are the alteration of the hydrologic regime and changes to a number of water quality parameters. In many cases, the observed changes in water quality conditions are directly related to the altered hydrologic regime that is established by the dam and operating regime of the project such as the conversion of a riverine (lotic) environment to a lake-like (lacustrine) environment.

In addition to direct impacts to water quality parameters, there are a number of second and third order impacts to water quality parameters. A major example is the change in dissolved oxygen regimes in the river vs the reservoir situation. In many situations, biological productivity in the reservoir will, in turn, affect dissolved oxygen concentrations both in the reservoir and downstream from the reservoir. Also, changes in land use patterns upstream from the reservoir will cause changes in water quality characteristics of inflow to the reservoir, thereby, causing changes to water quality both in the reservoir and in the river downstream from the reservoir. In both of these cases, the changes in water quality conditions are considered third order impacts and frequently are not directly attributable to the hydropower project. Thus, in developing baseline monitoring, mitigation plans, and construction and operational monitoring programs, it is frequently necessary to distinguish those parameters that are directly affected by the project and those that are indirectly affected. Responsibility for mitigation and/or remedial actions must therefore be determined.

Because many of the effects to biological and social effects are directly attributable to the altered hydrology and water quality conditions the assessment and prediction of the changes to these factors are essential components of the EIA and the construction and operational monitoring programs to assess the actual effects of the project. Therefore, development of a sound understanding of the existing hydrologic and water quality conditions is essential for predicting and evaluating the effects of dams on both hydrology and water quality. This manual is designed to assist in developing a comprehensive water quality monitoring program that will enable accurate prediction of potential effects on water quality and effective evaluation of the actual water quality effects resulting from construction and operation of hydropower projects.

1.2. Legal Framework in Nepal

The primary statute regulating water quality in Nepal is the Water Resources Act, 2049 (1992), specifically Articles 18, 19 and 20 of the Act. These sections provide for the fixing of quality standards for water resources, establishment of tolerance limits for the discharge of pollutants and reduction in adverse effects to water quality due to erosion, flood, landslide or similar other causes. In addition, the Environmental Protection Act 2054, (1997) provides for the prevention of discharge of wastes in such manner that degrades the environment including water, air and soil resources. Both acts provide for the establishment of rules and standards for regulating the discharge of pollutants to aquatic systems, and for the prevention of degradation to the resources.

At present, specific water quality standards regulating the effect of hydropower facilities on water quality have not been promulgated. However, some standards relative to certain aspects of hydropower development, particularly during the construction period have been established. The Department of Standards and Meteorology, within the Ministry of Industry, has issued tolerance limits for discharge of industrial effluents to surface waters and are presented in Table 1.

Table 1: Tolerance limits for industrial effluents discharged into inland surface waters

No.	Parameter	Tolerance Limit
1	Total suspended solids, mg/L	30 – 200
2	Particle size of total suspended particles	Shall pass 850 micron sieve
3	PH	5.5 – 9.0
4	Temperature	Shall not exceed 40 ^{o}C in any section of the stream within 15 meters downstream from the effluent outlet.
5	Biochemical oxygen demand for 5 days at 20 ^{o}C, mg/L	30 – 100
6	Oils and grease, mg/L, Maximum	10
7	Phenolic compounds, mg/L, Maximum	1.0
8	Cyanides (as CN), mg/L, Maximum	0.2
9	Sulfides (as S), mg/L, Maximum	2.0
10	Radioactive materials: Alpha emitters, c/ml, Maximum Beta emitters, c/ml, Maximum	 10^{-7} 10^{-8}
11	Insecticides	Zero
12	Total residual chlorine, mg/L	1.0
13	Fluorides (as F), mg/L, Maximum	2.0
14	Arsenic (as As), mg/L, Maximum	0.2
15	Cadmium (as Cd), mg/L, Maximum	2.0
16	Hexavalent chromium (as Cr), mg/L, Maximum	0.1
17	Copper (as Cu), mg/L, Maximum	3.0
18	Lead (as Pb), mg/L, Maximum	0.1
19	Mercury (as Hg), mg/L, Maximum	0.01
20	Nickel (as Ni), mg/L, Maximum	3.0
21	Selenium (as Se), mg/L, Maximum	0.05
22	Zinc (as Zn), mg/L, Maximum	5.0
23	Ammoniacal Nitrogen, mg/L, Maximum	50
24	Chemical oxygen demand, mg/L, Maximum	250
25	Silver, mg/L, Maximum	0.1

Some of these standards will likely apply to various aspects of construction activities, particularly related to fabrication of equipment used in the powerhouse and/or dam and to the housing of the labor force during the construction period. While these standards specifically address effluent discharge from industrial developments, some of the standards may also be applicable to water quality affects attributable to operation of the hydropower development. At least these standards provide a starting point for developing an appropriate set of standards for operation of hydropower developments.

A continuing target of both the Eighth (1992-1996) and Ninth Plan (1997-2002) of HMGN has been and continues to be providing citizens of Nepal with adequate and safe drinking water supplies. While the focus on drinking water standards and supplies is not directly relevant to hydropower development, the goal of maintaining and improving the quality of available water supplies that ultimately could provide drinking water is directly relevant to water quality standards. The Ninth Plan (HMGN, 1996) states that as part of the government's policy and implementation strategy "...maintaining the biological, physical and chemical standard of water distributed from various systems, the process of making it clean and hygienic will be adopted. A national code of conduct will be made prepared to maintain the quality of water; appropriate organization will be made responsible for regular monitoring of drinking water; organizational capability will be developed." By inference, maintaining the quality of water for drinking water will also affect how hydroelectric projects are designed and operated.

1.3. Need for the Manual

Because there is not currently a regulatory framework or an accepted set of water quality standards for evaluating the effects of hydropower development on water quality, a general manual that provides insight into the types of water quality effects that are attributable to hydropower developments and how to obtain appropriate information to evaluate and assess the effects needed. The following manual seeks to provide a framework for establishing effective monitoring programs that will enable:

- Accurate prediction of the effects of hydropower development on water quality, and

- Evaluation of the effectiveness of mitigation measures and operating regimes during construction and operation of a hydropower project.

1.4. Objectives of the Water Quality Manual

The objectives of this manual include:

- Brief discussions of the common effects of hydropower developments on water quality parameters along with potential measures to avoid or mitigate potential water quality impacts;

- Identification of water quality parameters for which information is necessary to adequately evaluated the effects of hydropower developments;

- Suggestions for developing effective water quality monitoring plans to be implemented during the baseline, construction, and operation periods of the project cycle;

- Protocols for an environmental audit to be conducted as per Environmental Protection Rules, 2054 (1997);

- Procedures for interpreting the results of the monitoring programs;

- Suggestions for establishing an institutional framework for water quality monitoring programs and review of those programs; and

- Suggestions for risk assessment where mitigation or management programs are ineffective and protocols for remedial actions.

In addition to the primary objectives delineated above, this manual also provides (as Appendices) identification and assessment of available water quality databases relative to rivers of Nepal, identification of water quality analysis laboratories and evaluation of their capabilities, and a list of suggested equipment and instrumentation for conducting an effective water quality-monitoring program and an environmental audit.

2. WATER QUALITY EFFECTS OF HYDROPOWER DEVELOPMENT

2.1. Relationship Between Water Quality, Hydraulics and Hydrology

Many water quality parameters are directly affected by the hydrologic regime in the river and the hydraulic character of the river within its channel. Other water quality parameters are influenced primarily by soil, geologic conditions, mineralization within the basin. With respect to the assessment of hydropower projects, major considerations in the prediction of impacts focus primarily on those parameters that are influenced by hydrologic and hydraulic changes that result from the project. Of particular importance is the influence of the reservoir on water quality conditions and is therefore a focal point for the assessment of impacts. Major changes that can be observed as a consequence of hydropower dams and reservoirs result from the retention of water for a period of time within a reservoir system. It is in the reservoir that physical, chemical and biological processes that occur within standing water may be realized and subsequently affect the quality of water downstream from the project facilities. The following discussion provides some ideas as to the kinds of changes in water quality parameters that frequently occur as a consequence of a hydropower project

2.2. Types of Hydropower Projects

In order to understand the potential impacts of construction and operation of hydropower projects on water quality conditions upstream and downstream of the projects, it is necessary to understand the different types of hydropower projects. The specific type of project and its proposed operating pattern will influence the water quality information, which is needed to fully assess the impacts of the projects (i.e. during the EIA phase). The type of project and its operating pattern will also define the extent of the water quality-monitoring program to monitor the impacts during construction and operation of these projects.

Hydropower projects in can be categorized into two types: the Run-of-River and Storage (ST):

The Run-of-River Hydropower Projects – These types of projects can further be divided into two categories: The Simple Run-of-River (ROR) and Pondage Run-of-River (PROR) projects. The Simple ROR projects will not have storage for providing daily regulation. Outflows from the projects will equal to inflows to the projects. The ROR projects will generally consist of a relatively low diversion dam, an intake, and a water conveyance system leading to a powerhouse. There are three alternatives for locating the powerhouses, and they include:

1. At downstream toe of the dam,
2. At a distance downstream of the dam on the same river, or
3. At the downstream end of a water conveyance system diverting water from the dam to another river basin.

For the projects with powerhouses located at the toes of the dams, the flow patterns with the projects will be identical to that without the projects. Therefore, there will be minimal impacts on the water quality with the construction and operation of the projects.

For the projects with powerhouses located at a distance downstream of the dam on the same river, most of water will be diverted through the water conveyance systems to the powerhouses, and only minimum flows will be maintained for the river reaches between the dams and downstream powerhouses. This will change flow regimes in these reaches with construction and operation of this type of projects, and consequently, will have significant impacts on the water quality in these river reaches. Many existing hydropower projects in Nepal consist of diversion dams and powerhouses located at a distance downstream of the dams to fully utilize the head potentials of the rivers.

For the projects with powerhouses located at downstream ends of transbasin water conveyance systems, only minimum flows will be maintained for the river reaches downstream of the dams. The impacts on flow regimes and water quality in these reaches will be similar to that of the river reaches between the dams and downstream powerhouses as discussed above.

With the transbasin diversion, flows in the river reaches downstream of the powerhouses will be increased. This change in flow regime will also have impacts on the water quality of the river reaches downstream of the powerhouses in other river basins.

The Pondage Run-of-River (PROR) type of hydropower projects will consist of regulation ponds formed by construction of dams. The ponds will provide storage capacity for daily regulation. Similar to the Simple ROR projects, the powerhouses can be located at one of the three alternative locations. With the regulation pondages, the projects can generate power during on-peak periods during the day to meet the peaking needs of the NEA's interconnected electric system. The powerhouses may be shutdown during off-peak periods, or maintain minimum downstream releases during these periods. This will change the flow regimes in the river reaches downstream of the dams, and thereby have significant impacts on the water quality with the construction and operation of these projects.

The Storage (ST) Hydropower Projects – This type of projects will generally consist of a relatively high dam to form a reservoir, which provides seasonal regulating storage capacity. With this storage capacity, the ST projects can store inflows in the wet seasons and reducing flows and flooding in the downstream reaches of the dams. In the dry seasons, the projects can increase downstream releases from the dams to increase power generation, water supply, and augment low flows in the river reaches downstream of the dams to improve the water quality. The projects can also provide peaking generating capacity and energy production for meeting system needs during the daily on-peak periods. The powerhouses can also be located in one of the three alternative locations as that with the Simple ROR and PROR projects.

The construction and operation of this type of projects will have substantially greater impacts on flow regimes and water quality than that for the Simple ROR and PROR projects. This is because that the ST projects will not only change the daily flow regimes and patterns in the river reaches downstream of the dams, it will also change the flow regimes and patterns on a seasonal basis due to the seasonal regulating capabilities of these projects.

2.3. Possible Effects on Water Quality and Mitigation Measures

2.3.1. Potential Effects During Construction Period

Generally, effects of construction on water quality in a river stem primarily from the discharge of wastewater (both construction wastewater and sanitary wastewater from workforce housing areas) to the adjacent river and runoff from construction areas.

Discharge of wastewater from construction areas that may affect water quality include discharge of water used to wash concrete mixing and hauling equipment, wash water used to prepare concrete aggregate, and other minor on-site discharges of water to the river system. Generally, the effect is an increase in suspended sediment loads and an increase in alkalinity of the water due to discharge of calcium carbonate ($CaCO_3$), a component of concrete. However, dissolved solids may also increase significantly as a consequence of runoff from the construction area. If excavated material is deposited in or adjacent to the river channel, suspended solids concentrations and dissolved solids concentrations may increase further. Of particular concern with deposition of spoil materials is the potential for increasing concentrations of heavy metals such as iron, manganese, copper, lead, and other heavy metals.

Deposition of suspended solids in the river channel downstream from the construction area may cause changes in the river channel if significant amounts of sediment is contributed to the river and may cause problems with spawning areas of fish in the downstream reach of the river.

Discharge of sanitary waste from work camps and other human sanitary facilities can affect Biochemical Oxygen Demand (BOD) in the river as well as increasing fecal coliform bacteria concentrations, an indicator of potential disease risk to downstream users. Suitable handling and treatment of sanitary wastes will significantly reduce the potential for adverse effects to water quality from this source.

Runoff from construction areas constitutes a more problematic situation. Potential water quality effects from runoff from construction sites include increases in suspended sediment emanating from erosion from disturbed areas (construction staging areas, excavated areas, quarries, access road construction, spoil disposal areas), flushing of oils, greases and other hydrocarbon lubricants from maintenance areas, and potential flushing of other hazardous materials used at the project site for construction purposes. Containment of such materials and installation of erosion barriers will significantly reduce the potential effects to water quality. Maintenance of the erosion control measures and containment facilities must be accomplished throughout the construction period.

2.3.2. Potential Effects During Operational Period

Most of the significant water quality effects are realized only after the reservoir has been filled and the project begins operation. At this time, the affected river has been partitioned into two major components: the Reservoir (upstream from the dam) and the downstream reach of the affected river. Basically, the physical and chemical changes that are incurred in the reservoir determine to a large extent the water quality effects realized downstream from the project. Appropriate modifications to the design of the dam, spillway, and power structures can avoid or eliminate many of these potential effects.

2.3.3. Potential Effects Upstream from the Reservoir

In general, a hydropower project cannot and should not directly affect water quality conditions upstream from the reservoir, either in the mainstream of the river or tributaries to the reservoir area. Any realized changes in water quality upstream from the reservoir are generally attributable to changes in land use patterns, changes in population distributions and changes in industrial or commercial installations in the upper river basin. Consequently, any changes in water quality conditions upstream from the reservoir could create changes in water quality in the reservoir and ultimately be reflected in changes in water quality downstream from the reservoir. Management of land use, population distribution and industrial development upstream from the reservoir is basically the only option available to minimize these third order impacts.

2.3.4. Potential Effects Within the Reservoir

Conversion of a free-flowing river to a lake-like condition dramatically changes the physical, chemical and biological processes occurring in the body of water. Aside from the alteration of the hydrologic regime, physical parameters associated with water quality that will be affected include water temperature, and suspended sediment.

The impoundment of a reservoir will change the temperature regime of the water body. This is due primarily to the increased volume of the water body and the heat retention capacity of the water. Changes that might occur within the reservoir are the establishment of thermal stratification during portions of the year due to the reduced mixing of surface and bottom waters. Thermal stratification normally occurs only in reservoirs that are greater than 10 m deep and have a fairly extended residence time in the reservoir. Because most chemical and biological processes are to some extent temperature dependent, thermal stratification can affect concentrations of other chemical parameters as discussed below.

The potential for thermal stratification or significant warming of water in the reservoir will depend on various characteristics of the reservoir such as total surface area, average and maximum depth, residence time, surface to volume ratios, and orientation of the reservoir relative to solar radiation. A simple analysis for determining whether or not a reservoir will become thermally stratified was developed by Ledec, Quintero and Mejia (1997) as presented in Box 1.

Box 1: A rapid estimate of stratification tendencies in a reservoir can be obtained with the Densimetric Froude Number (F). F can be calculated as:

$$F = 320 (L\backslash D)(Q/V),$$

Where L = Length of the reservoir (meters), D = mean reservoir depth (meters), Q = mean water inflow (cubic meters per second), and V = reservoir volume (cubic meters). If F is less than 1, some stratification is expected, the severity of which increases with a smaller F. When F is greater than 1, stratification is not likely. -- Ledec, Quintero and Mejia, 1997.

A common effect of a reservoir on water quality is that the temperature regime, particularly in the reservoir will be altered. Commonly, water temperature at the surface of the reservoir will increase over pre-construction conditions during the warm. Depending upon the relationship between the amount of water flowing into the reservoir and the amount of storage capacity, the increase in temperature at the surface may be significant. A consequence is that the temperature may exceed the temperature tolerance of the native aquatic species, leading to a change in the species composition in the reservoir. However, this is highly dependent upon the size and configuration of the reservoir. Generally, such changes are insignificant at projects that are designed to be run-of-river or pondage-run-of-river. The potential for significant changes in water temperature are generally associated with projects with large storage capacity and long retention times of water in the reservoir.

Reduction in suspended sediment concentrations between the upper end of the reservoir and the dam will occur as the inflow water loses its energy and larger particles in the suspended sediment and bedload settle to the bottom. The major concern with the reduction in suspended sediments through the reservoir is the accumulation of sediments at the bottom of the reservoir displacing the volume of water that can be stored in the reservoir.

The accumulation of sediments in the upper portion of the reservoir can also affect the habitat for fish and other aquatic species. Basically, the accumulation of sediments alters the conditions of the substrate such that the substrate may be unsuitable for spawning and/or rearing of the juvenile fish. Such changes may lead to an altered species composition with the loss of specialized riverine species in the reservoir. Again, this is highly dependent on the size and configuration of the reservoir/pond and is most likely to occur in larger storage projects.

Nutrient concentrations in the water will likely change due to increased biological activities associated with the ability of organisms to remain in the water column and absorb nutrients from the water. Depending upon nutrient concentrations in the inflow water, significant increases in biological productivity can reduce nutrient concentrations in the water and retain those nutrients in the reservoir area either as biomass or as organic material accumulated in the sediments. An example of the possible changes in concentrations of a nutrient (phosphorus) is given in Figure 1.

Increased biological activities, in turn, can cause significant changes in dissolved oxygen concentrations in the reservoir water. In cases where the reservoir is relatively deep and exhibits periodic thermal stratification, biological productivity in the upper layers of water will result in the settling of biomass to the bottom of the reservoir where decomposition processes utilize dissolved oxygen. Because the lower layers of water do not mix with the surface layers, the bottom layer of water may be depleted of dissolved oxygen. The lack of oxygen at the bottom of the river could result in conditions that alter the chemical reactions that occur in the water. Lack of oxygen at the bottom of the reservoir will also lead to anaerobic decomposition processes resulting in the generation of hydrogen sulfide and methane.

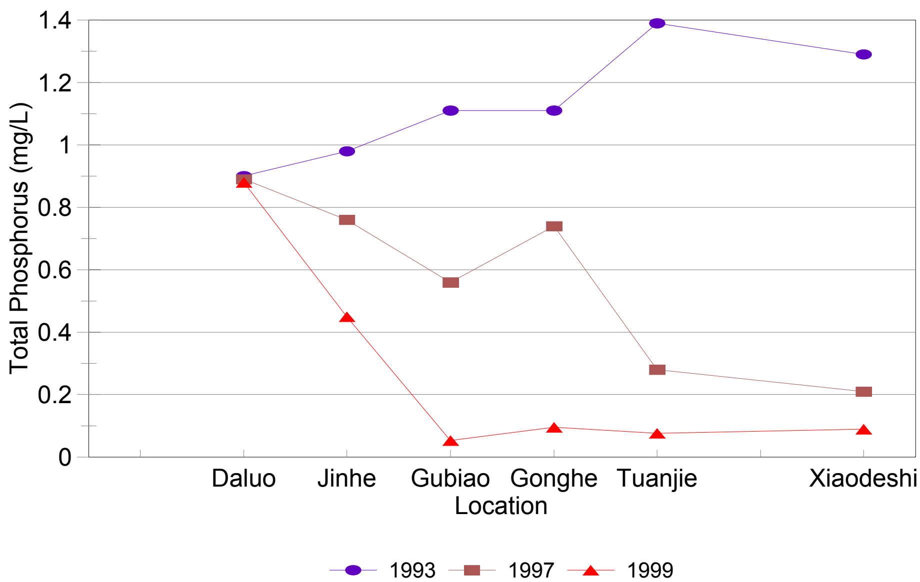


Figure 1: Concentrations of phosphorus through a reservoir system. Data for 1993 were obtained before closure of the dam. Data for 1997 were obtained immediately after the start of filling of the reservoir. Data for 1999 were obtained one year after the reservoir was filled. (Daluo is upstream end of reservoir, dam is between Tuanjie and Xiaodeshi). (Ertan ERP, 2000)

Low dissolved oxygen concentrations in turn may also mobilize heavy metals causing them to go into solution and ultimately be transported downstream. Loss of oxygen will also affect acidity and alkalinity balances, total dissolved solids, and the solubility of many man-made chemicals.

Primary measures to prevent adverse water quality impacts in the reservoir involve management of the drainage basin upstream from the project. This would include management of land use practices and patterns, provision of treatment of sanitary wastes, regulation of industrial, mining and commercial development, and introduction of agricultural practices.

Some measures to prevent thermal stratification in reservoirs, thereby reducing the potential for generation of low dissolved oxygen concentrations in the lower strata of the water column are also available. These consist primarily of mechanical measures designed to increase the mixing of hypolimnetic and epilimnetic waters. However, these measures are generally impractical for large reservoirs and require considerable operation and maintenance activities when used in small reservoirs.

2.3.5. Potential Effects Downstream from the Facilities

The more significant effects of a hydropower development on water quality, at least from the perspectives of ecological characteristics and human use, are generally realized in the river downstream from a hydropower development. The primary contributors to realizing these affects include the configuration of the dam and power station and the operating regime of the facilities. The magnitude of the changes in water quality parameters realized downstream from the project are attributable to the operating regime of the project which defines the hydrologic regime; physical, chemical, and biological processes that occur in the reservoir; and the configuration of the dam and power station including the morphology of the reservoir, location and elevation of the power intake structure, and position of the dam relative to the position of the power station. All of these factors must be taken into consideration when predicting the impact of a project, designing the dam and power station, establishing effective mitigation measures, and operating the power development.

Aside from the alteration of the hydrologic regime, three of the more common water quality parameters that are affected by a hydropower development in the downstream reach are water temperature, suspended sediment concentrations and dissolved oxygen.

Thermal characteristics of water in the reservoir, the configuration of the power intake, and the operating regime of the power station will have more or less impact on the thermal regime of the river downstream from the project. Changes in the thermal characteristics of the downstream occur as a consequence of the retention of water in the reservoir. When water is retained in the reservoir, the temperature of the water frequently increases due to the prolongation of exposure to solar radiation and ambient temperature. The longer water is retained in the reservoir, the greater the change in the thermal regime realized in the downstream reach. The changes that are realized may be either an increase or decrease in temperature (see below), and a change in the seasonal warming and cooling regime in the river. Increases in water temperature downstream from the project frequently occur when the power intake withdraws water from near the surface of the reservoir whereas decreases in water temperature occur when the power intake withdraws water from near the bottom of the reservoir (particularly in a reservoir that becomes thermally stratified).

Delays in the warming and cooling cycles of water temperature in the downstream reach also occur because of the high heat retention capacity of water. With the onset of spring and summer, water temperature tends to remain cooler in the reservoir for a longer period of time thereby delaying the warming process in the downstream reach. Similarly, in the fall, cooling of water in the reservoir is not as rapid as in the free-flowing condition and the downstream reach remains warm for an extended period.

In the situation where the reservoir becomes stratified, the thermal regime in the downstream reach will be dependent on the elevation of the power intake structure relative to the elevation of the thermocline in the reservoir. If the power intake withdraws water from the surface or epilimnion of the reservoir, water discharged through the power station will generally be warmer than in the preexisting condition. Similarly, of the power intake withdraws from near the bottom or from the hypolimnion, water discharged through the power station will be colder.

While the temperature regime in the river, in and of itself, is not necessarily considered an adverse condition, it is the changes in the biological community that are affected by those changes that can become significant. For example, the temperature regime of a river may affect the types of organisms that are able to survive in the affected reach (many species of fish for example are adapted to specific temperature ranges), the biological productivity within the reach (generally, biological production is positively correlated with temperature in aquatic systems), and the reproductive cycles of aquatic organisms downstream from the project (many fish species, for example, are stimulated to spawn within specific water temperature ranges and delays in attaining those temperature conditions will affect if and when the species spawn). It should be noted that although some species may cue reproductive cycles on water temperature, other species cue their cycles on changing hydrologic regimes that may or may not be correlated with seasonal changes in water temperature. Therefore, the significance of predicted changes in water temperature must be framed in reference to the biological requirements of organisms inhabiting the river downstream from the project.

Measures to avoid or mitigate for expected changes in water temperature downstream from a power station include modification of the elevation of the power intake structure, provision of multiple-level intake structures. (see Bizer, 1999)

Concentrations of suspended sediment is the second major water quality parameter that will be affected by a hydropower development. Many of Nepal's rivers have a high suspended sediment load, particularly during the summer, monsoon period. The cycle of high suspended sediment concentration is due to both melting snow in the mountains and increased precipitation during the monsoon periods. The amount of suspended sediments in the river may be exacerbated by deforestation in the upper basin and careless agricultural practices. In a free-flowing condition, suspended sediment is transported downstream with altering degradation and aggradation processes occurring throughout the river. As sediment is carried downstream from a particular location, other sediment is deposited in those areas from upstream. The imposition of a dam and reservoir in the river interrupts this process and as a consequence, sediments are removed from the downstream reach but are not replaced by sediments from upstream. While the deposition of sediments in the reservoir may be considered a mechanism to improve clarity of water in the downstream reach, the deposition process has a number of adverse ramifications. First, deposition of sediments in the reservoir will displace storage capacity in the reservoir and, if excessive, will reduce the power generating capacity of the reservoir or can fully fill the reservoir rendering the reservoir unusable.

Downstream from the dam and power station, flow in the river will continue to remove small particles of sediments from the river channel and, because no sediments are available to replace those that are carried away, the river channel will be cleared of small particles and eventually will degrade leaving only larger gravels and rocks. The removal of small sediments from the downstream reach can affect spawning habitat for fish as well as production of food for fish and other aquatic organisms.

Measures to avoid or mitigate the loss of suspended sediments in water downstream from the dam include provisions for periodic sluicing of sediments from the reservoir to the downstream reach. The process of sluicing of sediments from the reservoir achieves two objectives: removal of accumulated sediments in the reservoir and replenishment of sediments in the downstream reach.

A third water quality parameter that is frequently affected by hydropower developments is dissolved oxygen concentration in the downstream reach. Whether or not dissolved oxygen concentrations are affected depends on the dissolved oxygen regime in the reservoir and the location and elevation of the power intake. In situations where the reservoir becomes thermally stratified, biological productivity is high with correspondent decrease in dissolved oxygen concentrations in the hypolimnion, and the power intake is located near the bottom of the reservoir, water with low dissolved oxygen concentrations may be released to the downstream reach. In extreme cases, anoxic (no dissolved oxygen) water may be released from the reservoir. Since organisms require oxygen to survive, the diversity of aquatic organisms in the downstream reach may be significantly reduced. The assimilative capacity of the river may also be reduced if water with low dissolved oxygen concentrations is released from the dam.

Measures to avoid or mitigate such conditions are similar to those described for water temperature. However, a number of other measures are available to remediate these effects at existing reservoirs. Such measures include installation of aeration devices in the reservoir, injection of air or oxygen gas into the penstock, turbine blades or draft tube of the power station or installation of aeration weirs in the tailraces of the power stations (see Bizer, 1999).

2.3.6. Potential Effects Due to Increased Human Populations

A factor associated with hydropower development, but may not be considered a direct affect of the project, is the change in land use patterns upstream and downstream from the project. Changes upstream from the project may occur primarily as a consequence of an involuntary resettlement program that involves moving households and agricultural areas from areas within the reservoir to elevations above the maximum water level of the reservoir. Changes downstream from the project are likely to occur as a consequence of construction of an access road into otherwise inaccessible areas, changes in availability of water for irrigation, and the construction of industrial or commercial complexes in the vicinity of the project where electric power is readily available.

An increase in population along the margin of the river, particularly downstream from the project will likely increase nutrient loading of the river as a result of runoff from fertilized agricultural areas as well as discharge of sanitary wastes to the river from villages and towns that increase in size. Discharge of sanitary wastes to the river may result in increases in disease incidences thus creating a public health problem. Changes in agricultural use of the basin may be accompanied by increased use of fertilizers and pesticides that, in turn, may be flushed into the river channel and affect the survivorship of aquatic organisms or may be taken up by commercially important species thereby posing a further threat to human health.

Establishment of industrial enterprises along the river may result in the discharge of toxic or hazardous waste materials to the river thereby creating additional health problems both in the aquatic community and potentially in the human communities along the river.

An example of the impact of human habitation on water quality is exemplified by results of a 1988 study of water quality in the Bagmati River through Kathmandu. As shown in Figure 2, water temperature increases gradually from Sundarijal (location 1) to Khokna (location 7) as would be expected as the river descends from the mountains. Figure 3, however, demonstrates the inflow of biochemical oxygen demanding materials (BOD) to the Bagmati with the maximum concentrations occurring downstream of Kathmandu at Sundarighat (location 5) with a decline in concentrations at Chobar (location 6) and Khokna (location 7). In opposition to the increase in BOD through Kathmandu, dissolved oxygen concentrations (DO), see Figure 4, decline through the city with the lowest concentrations at Sundarighat (location 5) corresponding with the highest concentrations of BOD.

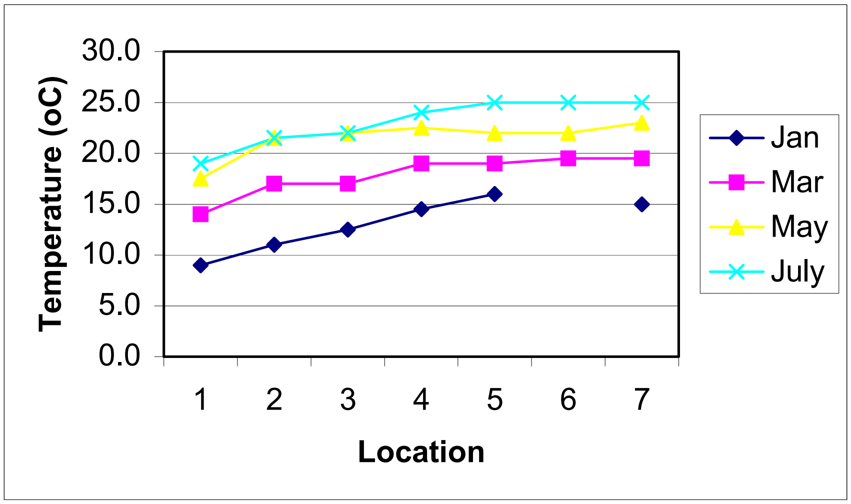


Figure 2: Water temperature in Bagmati River at seven locations through Kathmandu (FPAN-DISVI, 1988).

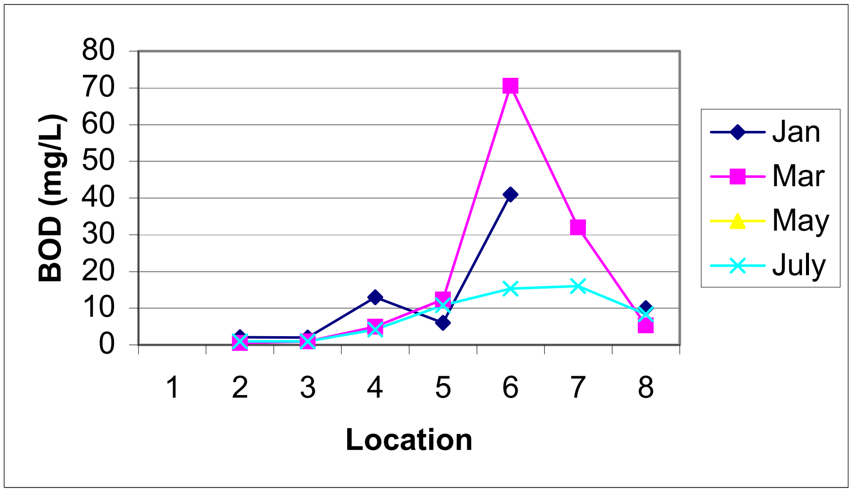


Figure 3: Concentrations of Biochemical Oxygen Demand in Bagmati River at seven locations through Kathmandu (FAPN-DISVI, 1988).

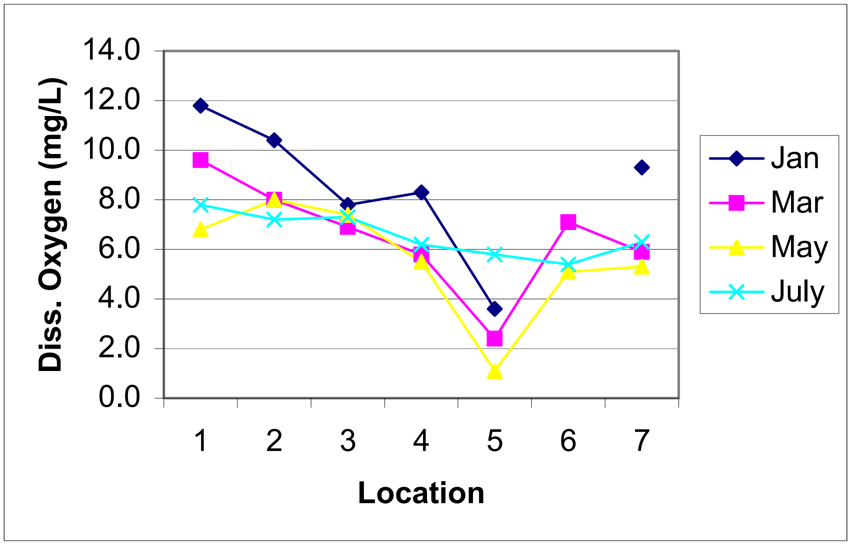


Figure 4: Dissolved Oxygen concentrations in Bagmati River at seven locations through Kathmandu (FPAN-DISVI, 1988).

In general, these types of impacts to water quality are considered third order effects and cannot be mitigated or avoided by structural or operational aspects of the project. Rather, the only effective measures to avoid such impacts involve management and training of the human population in the basin in such areas as improved agricultural techniques, improved treatment of sanitary wastes, and regulation of discharges from industrial and commercial enterprises.

2.3.7. Effects of Altered Water Quality on Structural Components of Facilities

In recent years, some hydropower projects have experienced structural degradation due to water quality characteristics. A 1987 study by the Committee on Materials for Concrete Dams, a committee of the International Commission on Large Dams (ICOLD), investigated the degradation of dams and other structural components that occurs because of water quality conditions in the river and reservoir. A conclusion of the report that dams located in high mountain areas where the underlying geology is igneous, siliceous or dense limestone, water draining into the reservoir may, because of the dissolved solids, may create a situation that could damage dam structures, particularly those constructed of concrete. Since all of the rivers in Nepal drain mountainous areas, a prudent component of the evaluation and monitoring of dams should be directed to water quality characteristics that could lead to structural damage to the dams and other components. This is particularly true for privately funded hydropower projects that are licensed for periods up to 25 years, which eventually will be turned over to HMGN for continued operation and maintenance.

Chemical concentrations that could lead to degradation of concrete structures include:

- Dissolved carbon dioxide that reacts with water to create carbonic acid which in turn can react with $CaCO_3$, a product of interaction of concrete with carbon dioxide, to form soluble calcium bicarbonate ($Ca(HCO_3)_2$;

- Sulfates which react with calcium hydroxide in the concrete to create compounds that have volumes that are greater than those of the constituents from which they are formed;

- Sulfides, such as hydrogen sulfide (H_2S) which react with water to create sulphuric acid that can react with concrete to reduce the strength of the concrete; and

- Various acids such as sulfuric, hydrochloric, nitric, carbonic, and free organic acids may react with various components of concrete to either erode the volume of concrete or reduce the strength of concrete. Introduction of various acids into a reservoir may be exacerbated in heavy industrial areas that are subject to acid rain.

To evaluate the potential for potential structural degradation due to water quality conditions, it is recommended that the following parameters be determined in the river water in order to design a dam and appurtenant structures that will withstand potential degradation from these conditions: pH, alkalinity or acidity, hardness, dissolved carbon dioxide, total dissolved solids, specific conductivity and water temperature. Values of these parameters can be used to calculate a saturation index that can be used to evaluate the potential for degradation of concrete due to water quality conditions as described in Box 2.

Box 2: A saturation index developed initially by Langelier in 1936 may be used to assess the potential for concrete degradation due to water quality parameters. The original index was reformulated by Morton in 1977 as follows:

$$LI = pH + \log C + \log A + 0.025T - 0.011\,S - 12.30$$

Where: LI = Langelier index; C = calcium hardness or calcium ion content expressed as equivalent $CaCO_3$ (mg/l); A = alkalinity expressed as equivalent $CaCO_3$ (mg/l), T = temperature in ^oC where T is between 0 and 25 ^oC; and S = total dissolved solids (mg/l) where S is less than 1000 mg/l.

A negative value of LI indicates potential problems with degradation of concrete due to water quality parameters (value of –1.5 = significant potential). Positive values of LI indicate low potential for degradation of concrete. (Committee on Materials for Concrete Dams, 1987)

3. RECOMMENDED PARAMETERS FOR INCLUSION IN MONITORING PLANS

Table 2 presents a list of water quality parameters for inclusion in water quality monitoring plans developed for baseline, construction and operation monitoring plans. This list comprises a minimum number of parameters for consideration. The specific conditions at a hydropower development site may dictate additional parameters.

Table 2: Water quality parameters for inclusion in water quality monitoring plans associated with hydropower developments.

Parameters	Pre-Construction	Construction	Operation	Audit
General Monitoring				
Water Temperature	Y	Y	Y	
Air Temperature	Y	Y	Y	
Dissolved Oxygen	Y	Y	Y	
Conductivity	Y	Y	Y	
Total Suspended Sediments	Y	Y	Y	
Total Dissolved Solids	Y	Y	Y	
PH	Y	Y	Y	
Assessment Monitoring (As Recommended During Consultation)				
Nitrate-Nitrogen	Y	Y*	Y*	Y
Ammonia-Nitrogen	Y	Y*	Y*	Y
Total Phosphorus	Y	Y*	Y*	Y
Heavy Metals (Fe, Hg, Mn, As, Pb, Cd, Na, K, Cr)	Y	Y*	Y*	Y
Biochemical Oxygen Demand	Y	Y	Y*	Y
Chemical Oxygen Demand	Y	Y	Y*	Y
Total Coliform Bacteria	Y	Y		
Fecal Coliform Bacteria	Y	Y	Y*	Y
Alkalinity (as $CaCO_3$)	Y		Y*	Y
Hardness (as $CaCO_3$)	Y		Y*	Y
Chloride	Y	Y	Y*	Y
Sulfates	Y		Y*	Y
Oil and Grease	Y	Y	Y*	Y
Pesticide Scan	Y		Y*	Y
Dissolved CO_2	Y		Y*	Y
Chlorophyll a[1]	Y		Y*	Y

[1] Y* = short duration monitoring, with quarterly sampling

4. DESIGN OF WATER QUALITY MONITORING PROGRAMS

Assessment of potential impacts of a hydropower development to water quality first requires an effective plan to acquire sufficient baseline information to make the assessments. At the time construction activities begin, a modified monitoring program is necessary to evaluate the effectiveness of measures to prevent adverse effects to water quality. Ultimately, additional modifications to the monitoring plan are needed to evaluate the actual effects of the project on water quality and to enable identification of unanticipated effects and/or ineffective protection measures. The first monitoring plan, to develop a baseline of information, should be a component of the Terms of Reference (TOR) developed within the Environmental Impact Assessment (EIA) process. The second and third modifications to the baseline monitoring program are to be presented in the Environmental Management Plan (EMP) which is a part of the EIA report.

The following discussion presents guidelines for preparing the baseline, construction and operational water quality monitoring plans for inclusion in the TOR or EIA as appropriate.

4.1. Consultation Requirements

Water quality monitoring programs, for obtaining baseline information (i.e. presented in the TOR) and for evaluating the effects of construction and operation of the hydropower development (i.e. presented in the EIA), must be prepared by the developer in consultation with appropriate governmental agencies. As appropriate, other interested and concerned organizations and individuals may participate in the planning process.

Throughout implementation of a water quality monitoring program, continuing dialogue, particularly with governmental agencies are highly recommended. As appropriate, other interested and concerned organizations and interested and affected parties may be consulted. Such consultation may result in modification of the monitoring program if preliminary results indicate that measurement of some parameters may be suspended or other parameters should be incorporated into the monitoring programs.

4.2. General Format for Presentation of Monitoring Plans

The following discussion provides a generic format for presenting water quality monitoring plans. For each section of the plan, the discussion provides some suggestions for the information that should be presented and discussion of how various components are selected for inclusion in the plan.

4.2.1. Purpose

Generally, the statement of purpose for a water quality monitoring program is fairly straightforward. Through the development cycle, three basic monitoring programs will be designed and implemented corresponding to the baseline description period (EIA), construction period, and operational period.

The primary purposes of the baseline monitoring program are twofold: First, the baseline monitoring program should provide sufficient information to enable accurate (justifiable) predictions of potential effects of the hydropower project on water quality parameters; second, the baseline data set will provide the "standard" against which project effects and/or mitigation effectiveness can be determined. Obviously, it is necessary to determine the starting point condition to determine if changes occur.

The purpose of the water quality monitoring program for the construction period, likewise, can serve two purposes: First, the program should be designed to enable evaluation of the effect of various construction activities and construction related facilities on water quality; second, certain components of the program can provide further baseline information for determining the effect of project operation on water quality both in the reservoir and downstream.

The purpose of the final water quality monitoring program to be implemented during operation also has two purposes: First, data collected during the operational period are compared with the baseline data to determine if projections made in the EIA are accurate and mitigation or avoidance measures are effective; second, the monitoring program can be used to determine if changes occur during the operating period that might require attention and can be used as a basis to determine the source of any pollutants.

4.2.2. Sampling Design

Design of the water quality monitoring program is key to obtaining a useful set of information for describing baseline conditions and measuring the effects of construction and operation on those conditions. Thus, the sampling design presented in the monitoring plans is the most important part of the plan.

4.2.2.1. Duration

The duration of the water quality monitoring programs will vary according to the stage in project development.

For baseline monitoring, the minimum length of time necessary for basic understanding of cycles in water quality parameters is one year. The baseline monitoring program should provide sufficient information on all parameters included in the monitoring program to demonstrate annual cycles in concentrations or conditions. While the data set should provide at least one full year of sampling, continuing monitoring for longer periods would facilitate understanding of year-to-year variation in those parameters. Consequently, the baseline monitoring program should be implemented for as long a period as possible given the schedule for project construction and completion.

Determination of the duration of the construction period monitoring program should correspond to the construction period, including preparatory period (i.e. access road construction, site preparation, etc.), dam and powerhouse construction, and rehabilitation of construction areas following construction. In addition to monitoring the effects of construction, continuation of monitoring parameters included in the baseline program will provide additional foundation for measuring the effects of the project once it becomes operational.

The duration of the monitoring program to be implemented during operation of the project will depend upon specific conditions at the project. For some parameters, the monitoring program could extend throughout the life of the project. For other parameters, sampling for a period of up to 5 years will provide an adequate basis for evaluating the effect of the project.

4.2.2.2. Sampling Frequency

As defined above, recommended parameters for inclusion in the baseline, construction period, and operational period include two groups: Those for general monitoring and those for assessment monitoring.

During the baseline period (EIA preparation), parameters included in general monitoring should be measured on at least a biweekly basis, preferably on a weekly basis for one full year. Parameters included for the assessment monitoring include some parameters that should be measured on a monthly basis, with the remainder measured on a quarterly or seasonal basis through the planning phase of the project.

The sampling frequency during the construction period, particularly for parameters that may be affected by construction activities should be measured at least on a monthly basis throughout the construction period. Parameters that are included in the general monitoring program and contribute to the baseline descriptions should be measured at the same frequency as determined for the planning (EIA) phase.

The sampling frequency of parameters during the operational phase may be divided into two periods: Initial effects and long-term effects. The basic operational monitoring program should include sampling of the various parameters on at least a monthly basis for a period of up to 5 years after initial operation of the project. Once the initial period expires, the monitoring program may be reduced to include the only a few basic, indicative parameters. If significant changes in one or more of the basic monitoring parameters occur, expansion of the monitoring program for a specified period of time may be necessary to identify the cause of those changes. In general, during the long-term monitoring phase, the basic set of parameters should be sampled on a monthly basis.

4.2.2.3. Sampling Locations

The number of sampling locations for water quality analysis will depend on the particular project configuration. For single projects, whether it is run-of-river or pondage run-of-river, located on a single river, a minimum of three sampling locations is needed for both baseline monitoring and construction and operation monitoring. With larger and more complex projects, such as a storage project with a relatively large reservoir, the number of locations included in the monitoring program will be determined on a case-by-case basis. Figure 5 depicts the minimum number of locations and the relative location of the sampling sites for a number of configurations of hydropower projects commonly planned in Nepal. As indicated in the figure, the number of sites that should be included in the baseline plan will depend on the size of the project, the existence and length of any reach of river bypassed by the penstock and power station, the presence of tributaries, and interbasin diversions.

For construction monitoring, additional locations may be included to enable evaluation of possible pollutants from various areas of the construction facilities. For example, an additional location might be downstream from construction staging areas or downstream from labor camps. If some of these facilities are located on tributaries of the main river, the samples should be collected upstream and downstream from those facilities.

For operation, the number of sampling locations may be reduced to significant sites. However, the monitoring program should include, at a minimum, samples collected both upstream from the reservoir and downstream from the power station (assuming there is no interbasin diversion and the reservoir is relatively small). Factors to consider in determining the sampling locations for monitoring operation include: size of the reservoir, residence time of water in the reservoir, diversion reach length, presence of tributaries within the reservoir or d/s of dam, length of bypassed reach, etc.

For projects that involve interbasin diversion, sampling locations during construction and operation should include at least upstream and downstream from the dam on the source river and upstream and downstream from the powerhouse tailrace on the receiving river.

4.2.2.4. Sample and Data Analysis

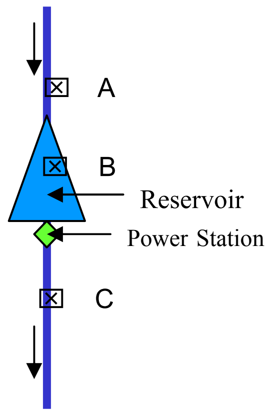
To the extent possible, parameters recommended for the monitoring program, particularly those included in the general monitoring group, may be measured in the field with appropriate instrumentation and/or field kits. The remaining parameters generally require transport of water samples to a laboratory for analysis. For parameters that require laboratory analysis, sample bottles and containers with appropriate preservatives, if necessary, can normally be obtained from the laboratory. A preliminary list of water quality laboratories (private, governmental and non-governmental) is presented in Annex 1. A list of possible field equipment to conduct the monitoring program is included in Annex 2. As with any field or laboratory instrumentation, it is necessary to standardize the equipment according to manufacturer specifications throughout the field effort.

All samples should be clearly labeled with an identifying number and all pertinent information regarding the sample recorded on separate data sheets for each location and sampling time. A sample data sheet for use in the field should be presented as part of the proposed monitoring plan. In addition to the field data sheets, it is highly recommended that a "Chain of Custody" form also be used to document delivery of the samples from the field to the laboratory. Samples collected for analysis in the field should be taken to the laboratory as soon as possible. The length of time a sample may be held prior to analysis can be determined in consultation with the laboratory.

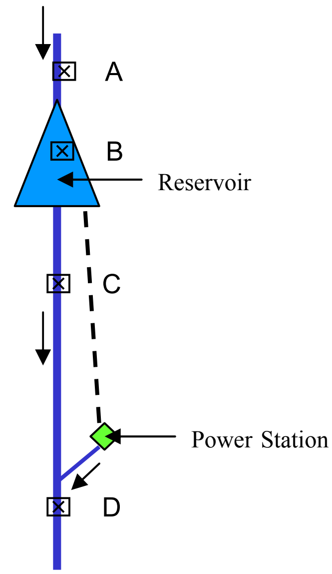
The water quality monitoring plans should include a section on the logistics of data collection and sample handling. Information to be included in the water quality monitoring plans should include the field and laboratory procedures that will be used to analyze the samples. There are a number of "Standard Methods" for analysis of water quality. The particular methods that are to be used should be cited in the monitoring plan.

Statistical analysis of the results of the water quality analysis will generally vary from phase to phase and project to project. For baseline monitoring, particular attention should be given to identifying seasonal cycles and longitudinal trends. The data may then be used to estimate how the project will affect each parameter. In some cases, it will be appropriate to use the data for calibration of one or more water quality simulation models. Relatively simple models are available to determine the effect of a project on water temperature and dissolved oxygen in the river.

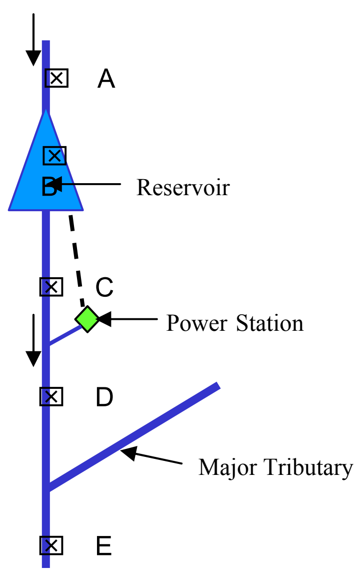
Most likely, the engineering feasibility study will include an analysis of sediment accumulation in the reservoir. If a model is used to determine the accumulation of sediments in the reservoir, results of the model may also be used to estimate the change in suspended sediment concentrations downstream from the river. Engineering feasibility studies may also determine degradation and aggradation processes in the downstream reach. In more complex systems a full water quality model may be used for the evaluation. Such models might include WQRRS or DYRESM. A number of other water quality models are also available for impact evaluation.



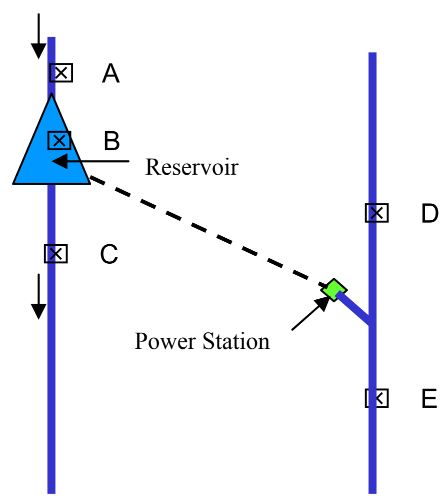
Run-of-river dam and power station. Sampling locations include: upstream from reservoir (A), within reservoir (B) and downstream (C) from power station.



Run-of-river dam and power station with dewatered reach between dam and power station. Sampling locations include: Upstream of reservoir (A), within reservoir (B), within dewatered reach (C), and downstream from tailrace confluence with river (D).



Run-of-river dam and power station with dewatered reach and major tributary downstream of tailrace. Sampling locations include: upstream of reservoir (A), within reservoir (B), within dewatered reach (C), downstream from tailrace (D), and downstream from tributary (E).



Run-of-river dam and power station with interbasin diversion. Sampling locations include: upstream from reservoir (A), within reservoir (B), downstream from dam (C), upstream from tailrace (D) and downstream from tailrace (E).

Figure 5: Locations of sampling sites at different types of hydropower projects.

The most important component of the data analysis during the construction and operating periods is comparison of the pre-project condition or baseline condition with the construction and operating conditions. Such analysis will determine if and by how much impacts to water quality have occurred and are used as determinants of the effectiveness of any mitigation measures that have been incorporated into the project configuration. As construction and operating data are acquired over the duration of the monitoring program, additional analysis of trends in water quality changes may be identified from the monitoring data. Such trend analysis might include seasonal changes as well as changes that occur gradually through the years.

4.2.2.5. Identification of Water Quality Laboratory

An important component of the water quality monitoring plans is the identification of the institutions responsible for collecting the samples and for conducting the analysis of those samples. Measurements of water quality parameters in the field and collection of the water quality samples for analysis in the laboratory may be performed by trained field technicians employed by the environmental consultant. Samples collected for laboratory analysis should be conveyed to the laboratory according to the protocol furnished by the selected water quality laboratory.

Chapter 6 of the Environmental Protection Rules 2054 (1997) provides for the certification of non-governmental laboratories and states that the Ministry of Population and Environment maintain a list of standard laboratories. If appropriate the list of standard laboratories may be obtained from MOPE. As a starting point, a provisional list of laboratories capable of analyzing water samples is presented in Annex 1 to this manual.

4.2.2.6. Quality Control

An issue that should be addressed in the water quality monitoring plans relates to quality assurance that the data presented are accurate and reliable. An acceptable quality assurance program will consist of both external and internal controls by the laboratory providing the analytic evaluations of samples.

First, the developer and/or the environmental consultant should implement an external quality control procedure. The procedure should at least include submittal of duplicate samples from one or more locations on each sampling date. These samples should be blind samples such that the water quality laboratory is unaware of which samples are duplicated. A second possible component of an external quality control procedure could consist of periodic submittal of duplicate samples to a second laboratory, one not responsible for the routine analysis process.

Second, the quality control procedures adopted by the water quality laboratory should be presented in the plans. An acceptable procedure should include duplication of samples by the quality control officer of the laboratory after submittal of the sample to the laboratory but prior to delivery to the laboratory technicians. The procedure should also include submittal of blank samples and "spiked" samples (samples with known concentrations of a parameter) to the laboratory technicians for analysis. Reports from the laboratory should include results of the internal quality control procedure for review by the developer/environmental consultant and the reviewing agencies.

4.2.2.7. Reporting

Reporting of water quality data will be dependent upon the phase of the water quality monitoring program. Data and analysis of those data obtained during the pre-construction phase are to be presented in the EIA. As appropriate raw water quality data should be presented with the EIA to enable independent evaluation of the results. A condition of the TOR may include a requirement for submittal of the water quality data in a standardized format for incorporation into a country-wide data base. The water quality data should be submitted with the EIA.

Reporting of results of the construction and operation monitoring program will also be submitted to the concerned agencies for review. The schedule for reporting the data will be negotiated as part of the approval of the EMP and will likely become conditions of the license to construct and operate the project. An appropriate schedule for reporting of results from the monitoring of construction activities would be on a quarterly basis. This will depend on the monitoring program itself and the frequency that samples are being collected.

Reporting of results of operation monitoring will likely be divided into two phases: an initial phase for a period up to five years with reporting on a semiannual basis and a second period following the initial period with reporting on an annual basis.

4.2.3. Regulatory Audit

The Environmental Protection Rules, 2054, state that two years after the commencement of service relating to the implementation of a proposal requiring an EIA, MOPE shall carry out an auditing of the environmental impact of the implementation of the proposal. The environmental audit procedures should be communicated to the hydropower developer to inform them of the procedures and to remind them that the environmental audit is a compulsory component of the hydropower development process.

In developing the regulatory audit procedure for a given hydropower project, MOPE should specify the following areas:

4.2.3.1. Purpose

The comprehensive audit will cover all aspects of engineering, environmental and social considerations regarding the project. With respect to water quality, the regulatory audit will seek to determine if projections of the EIA are accurate and whether or not measures to mitigate anticipated adverse effects are effective. Thus, the objective of the regulatory audit of the water quality monitoring program is to confirm the results of the monitoring program are accurate.

4.2.3.2. Acquisition of Information and Sampling Design

The regulatory audit of water quality monitoring will consist of two components: first, the audit will consist of a detailed review of data reported by the developer and construction contractor, including a review of the quality control procedures and results implemented by the developer; second, the audit will consist of an independent analysis of water quality conditions at the project site. This will consist of acquisition of measurements and samples in the same manner and location defined in the EMP. An independent laboratory, one not involved in the continuing monitoring program, should be selected to analyze the samples.

Selection of the laboratory may consist either of using the governmental laboratory within the DHM or another private laboratory.

4.2.3.3. Analysis

Analysis of the results of the regulatory audit will consist of two factors: first, the data will be compared with available water quality standards established for hydropower projects; second, the data will be compared with results of the monitoring program submitted by the developer.

4.2.3.4. Presentation and Reporting

Results of the water quality component of the environmental audit are to be included in the environmental audit report submitted to the MOPE.

5. GUIDELINES FOR REVIEW OF WATER QUALITY MONITORING PLANS AND RESULTS

Under the EIA process for HMGN, review of water quality monitoring plans and results are specified for four phases of the project. Initially, the proposed water quality monitoring plan to acquire baseline data for evaluation of potential impacts may be reviewed by DOED, MOWR, and approved by MOPE through the process of approval of the TOR for the EIA. Second, results of the baseline or pre-construction monitoring program and the accompanying evaluation of potential water quality effects and proposed water quality mitigation measures must be reviewed and approved by DOED, MOWR, and MOPE through the review and approval process of the EIA. The review of the EIA will also include review and approval of the water quality monitoring plans for the construction and operational phases of project development as defined in the EMP. The third stage review involves review and evaluation of results of the monitoring program conducted during the construction period. Finally, the fourth stage review involves review and evaluation of results of the monitoring program conducted during the operational period.

As appropriate, other agencies within HMGN, private organizations, individual stakeholders, and other interested parties should be invited to review the monitoring plans and results at all stages of the environmental assessment process and monitoring of project activities. In particular, the DHM should participate in the review process because it is responsible for acquiring information on hydrology and water quality from rivers throughout Nepal.

5.1. Review of Water Quality Monitoring Plans

5.1.1. Plan Included in Terms of Reference

The initial water quality monitoring plan submitted by a developer/environmental consultant for a hydropower development will be included in the TOR for the EIA process. MOPE is the primary agency responsible for approval of the water quality monitoring plans as a part of the TOR report. However, as appropriate, DHM and other agencies may participate in the review process, as they should have been consulted by the developer/environmental contractor prior to development of the plan.

Questions to consider during the review of the baseline water quality monitoring plan should include the following:

- Will the proposed parameters provide an adequate basis for describing the water quality conditions in the river in its current state?

- Will the proposed sampling locations enable adequate evaluation of the potential effects of the project?

- Will the frequency of sampling of each parameter enable description of seasonal annual variation in water quality conditions and provide a basis for determining the seasonal and annual effects of the hydropower project?

- Are the laboratory procedures for analyzing the water samples acceptable?

- Is the quality control program adequate?

5.1.2. Plans Included in EMP

As with the water quality monitoring plan included in the TOR, DOED, MOWR, and MOPE will also review the water quality monitoring plans for the construction period and the operational period. These plans are to be incorporated as part of the EMP that is submitted as a component of the EIA. As appropriate, DHM and other resource agencies within HMGN, private organizations, individual stakeholders, and other interested parties may participate in the review of the monitoring plans.

Questions to be considered in reviewing the monitoring plan for construction include:

- Will the parameters to be measured enable determination of potential effects of construction activities on water quality conditions?

- Is there consideration for expanding the baseline water quality data set for use in evaluating the actual effects of the project on water quality?

- Will the sampling locations enable determination of the sources of any contaminants that might be introduced to the river as a consequence of construction activities?

- Will the sampling locations and frequencies of measurements enable evaluation of the effectiveness of mitigation measures that are implemented during the construction period?

- Are the field and laboratory analytic procedures suitable?

- Is the proposed frequency of reporting the results sufficient to be able to determine water quality impacts and, if occurring, implementation of remedial measures?

- Is the proposed quality control procedure satisfactory?

- Is the reporting protocol for the monitoring program acceptable?

Questions to be considered in reviewing the monitoring plan for the operational period include:

- Will the parameters proposed in the monitoring plan enable evaluation of the effectiveness of any water quality mitigation measures proposed by the Developer/Environmental consultant?

- Are the proposed sampling locations appropriate for determining the effect of the development on water quality conditions?

- Is the frequency of sampling sufficient to enable identification of potential water quality problems prior to them becoming significant problems?

- If a two-phase monitoring program is proposed for the operational period, is the first phase sufficiently long to enable determination of actual water quality impacts and the effectiveness of any mitigation measures?

- Is the quality control procedure satisfactory?

- Is the reporting protocol (particularly, the frequency of reporting) acceptable?

- Is a provision for modification of the monitoring program appropriate for the project?

5.2. Interpretation of Monitoring Results

5.2.1. Pre-Construction Phase

The basic presentation and interpretation of water quality information obtained during the pre-construction, EIA phase of project development is primarily the responsibility of the developer/environmental contractor. The interpretation will focus on two primary components: water quality conditions in the river in its current condition (i.e. description of the baseline condition) and projections of any anticipated changes in water quality conditions through construction and operation of the project.

Review and interpretation of water quality data presented in the EIA will be evaluated as per the Environmental Protection Rules, 2054 (1997). In addition, DHM and other interested parties may participate in the review process.

When reviewing water quality analyses presented in the EIA, the following questions should be considered:

- Do the results comply with the specifications defined in the TOR for monitoring water quality parameters?

- Do the results adequately describe existing water quality conditions in the river prior to project construction?

- Do the results demonstrate seasonal and annual variation in water quality conditions?

- What are the potential effects of construction activities on water quality?

- If adverse water quality impacts are expected, are the proposed mitigation measures and water quality management programs appropriate and what is the probability that the measures will be effective?

- What are the potential effects of operation on water quality in the reservoir and downstream from the reservoir?

- If adverse water quality impacts are expected, what are the proposed mitigation measures and will they be effective?

- If there is some uncertainty pertaining to potential water quality impacts or the effectiveness of a mitigation measure, what mechanism is available to remedy any unforeseen impacts or failures in the mitigation measures?

5.2.2. Construction Phase

The developer/environmental consultant is required to conduct a water quality monitoring program during the construction phase. As discussed previously, some parameters may be monitored primarily to extend the baseline data to describe water quality conditions in the river prior to filling of the reservoir and operation of the project. However, the more important component of the construction phase monitoring program will focus on the effectiveness of measure to manage contamination of water in the river resulting from various construction activities.

Review of the reports of the water quality monitoring program should consider the following questions:

- Are results for all parameters defined in the water quality monitoring plan for the construction phase presented in the report?

- For each parameter measured, is there evidence that construction activities have led to changes in water quality in the river downstream from the construction site(s)?

- Based on the results presented, is the management of runoff from the construction sites effective?

- Are any of the results unexpected in that they indicate deviations from previous measurements; are significantly different from baseline data, or are significantly different from expected results?

- If deviations from previous measurements are detected or significant differences are present in the results, is there an explanation of why those differences have occurred?

- Has the developer/environmental consultant proposed remedial measures to correct the deviations or differences if it is clear that the differences are due to actions of the construction contractor?

5.2.3. Operational Phase

Results of the water quality monitoring program implemented once a project becomes operational are to be reviewed based on the baseline conditions, the effectiveness of any mitigation measures and comparison with what conditions were expected as set forth in the EIA. In conducting the review, the reviewer must consider whether or not any changes in observed water quality conditions constitute a significant degradation or improvement in water quality of the river. If some water quality parameters differ from expectations, the reviewer must also consider whether or not those changes are acceptable based on the analytic procedures used in making those predictions. This consideration must be made because many analytic processes may not be able to accurately predict future conditions because of the inherent variability of environmental conditions.

When reviewing results of the monitoring program conducted during the operational phase of the project, the following questions should be considered:

- Are the results presented in the report complete?

- Are the results compatible with base conditions and predictions of water quality conditions presented in the EIA?

- Do seasonal changes observed in the results consistent with anticipated seasonal changes as described in base conditions and anticipated conditions?

- Are there significant changes in one or more parameters from reporting period to reporting period?

- Has the developer provided explanations of why have any observed changes occurred?

- Are the changes due to the facilities and/or operation of them?

- If, after several reporting period, certain water quality parameters indicate a gradual change, has the developer explained why is that trend(s) occurring?

- If significant, unexpected changes in water quality conditions have occurred that are attributable to facilities and/or operation, has the developer suggested any measures to adjust facilities or operating regimes to remedy the problem?

6. INSTITUTIONAL ARRANGEMENTS

The responsibilities for conducting and reviewing various components of a water quality monitoring program are as follows:

Component	Responsible Agency
Developing the Baseline Monitoring Plan:	This aspect is the responsibility of the developer/environmental consultant in consultation with at least the DOED, MOWR, MOPE and DHM. Review and approval of the monitoring plan, as a part of the EIA report, shall be done as per Environmental Protection Rules, 2054.
Implementation of the Baseline Monitoring Plan:	Responsibility for implementing the baseline monitoring plan is the responsibility of the developer/ environmental consultant.
Presentation of Baseline Monitoring Results:	The developer/environmental consultant is responsible for submission of the baseline results to the concerned government agencies.
Preparation of Construction and Operational Monitoring Plans:	Development of the construction and operation monitoring plans is the responsibility of the developer/environmental consultant. Review and approval of the monitoring plan, as a part of the EIA report, shall be done as per Environmental Protection Rules, 2054.
Implementation of Construction Monitoring Plan:	Implementation of the construction monitoring plan is the responsibility of the developer/environmental consultant. Review of the monitoring program shall be done as per Environmental Protection Rules, 2054.
Implementation of Operational Monitoring Plan:	The developer/environmental consultant is responsible for implementation of the monitoring plan. Reviewing of the monitoring activities shall be done as per Environmental Protection Rules, 2054.
Implementation of the Environmental Audit:	MOPE shall carry out an audit of the completed project two years after the project is in operation.

7. RISK ASSESSMENT AND REMEDIATION

Throughout the development, implementation and review of baseline, construction, and operating water quality monitoring programs, all parties involved in the process must be aware that several risks that water quality conditions could be degraded. Such degradation may be the result of inaccuracies in the impact assessment process, failure to detect potential water quality impacts, or external factors that were not anticipated in the EIA process. Discrepancies with anticipated water quality conditions may also stem from mitigation measures that are ineffective. In general, non-compliance with expected water quality conditions may be attributable to one of the following conditions.

7.1. Non-compliance with Environmental Impact Predictions

7.1.1. Risk

Although there is considerable experience throughout the world with predicting the effects of hydropower projects on water quality conditions, the accuracies of these predictions are frequently dependent upon the particular methods used to make the predictions, specific morphological conditions at the project locations and in the respective rivers. Regardless of the particular analysis presented in the EIA, there remains a risk that the predictions are unrealized.

7.1.2. Responsibilities for Remediation

In some cases, the unanticipated impacts may not be significant. However, if the impacts are significant it may be desirable or necessary to implement remedial measures to rectify any adverse effects. During construction, most adverse impacts to water quality are generally attributable to activities in and around the construction areas. Consequently, the developer is generally responsible for implementing measures to remediate the problems. During operation, changes in water quality parameters may or may not be attributable to the operation of the facilities. In that case, it is the responsibility of the developer to determine the source of the non-compliance. If the changes are not due to the hydropower facilities or operation of those facilities, determination of responsibility for remediation should be determined as per prevailing laws.

7.2. Non-Compliance of Mitigation Measures

7.2.1. Risk

Integration of measures to avoid or mitigate adverse effects of a hydropower project to water quality may be incorporated into the design of the project and become a condition of a license to construct. However, there is a risk that, after incorporation into the project facilities and/or operating regime, the mitigation measures prove ineffective. This may result from insufficient information for design of the measure or unexpected conditions within the reservoir.

7.2.2. Responsibility for Remediation

In the event that a mitigation measure is shown to be ineffective, responsibility for implementing an alternative mitigation measure is generally with the developer. However, such revisions to the mitigation measure must be made in consultation with concerned government agencies and interested and affected parties. Depending upon the specific conditions that led to the ineffectiveness of the mitigation measure, the developer may negotiate one of several options including: implementation of an alternative measure or modification of an operating regime. However, the actual measure to be adopted must be mutually agreeable to both the developer and the governmental agencies.

Annex 1: Available Laboratory Facilities

A large number of water quality laboratories are located in Kathmandu with only a few located outside the Kathmandu Valley. In selecting a laboratory for conducting analysis of water samples to support the Environmental Impact Assessment or conduct the construction and operation monitoring programs it is important to recognize the capabilities of each laboratory.

The following is a list of laboratories that have been identified. The list is subject to change as more laboratories are established and become accredited. Not all of the laboratories identified below are accredited. However, this is likely to change in the future.

The capabilities of some of the laboratories are presented following the list of laboratories. The descriptions of the laboratories will be expanded as information from other laboratories is acquired.

Water Quality Laboratories in Nepal

The following are laboratories located in Nepal. The majority are located in Kathmandu. (R = Reviewed, C = Certified) The capabilities of reviewed laboratories are presented in succeeding section.

<u>Governmental</u>

1. Department of Hydrology and Meteorology - R
2. Central Division of Soil Science
3. Department of Mines and Geology
4. Soil and Water Laboratory, Department of Soil Conservation and Watershed Management
5. Nepal Bureau of Standards and Meteorology
6. Forestry Research Division
7. Ground Water Supply Project, Department of Irrigation
8. Horticultural Development Project
9. Central Food Research Laboratory

<u>Academic</u>

1. Central Department of Chemistry, Tribhuvan University
2. Central Department of Botany, Tribhuvan University
3. Department of Physics, Trichandra Campus
4. Institute of Engineering, Pulochowk

<u>Research Institutes</u>

1. Royal Nepal Academy of Science and Technology
2. Research Center for Applied Science and Technology
3. Lumle Agricultural Center (Pokhara)
4. Pakhribas Agricultural Center (Dhankuta)

<u>Private/Non-Governmental Organizations</u>

1. The Everest Chemical Laboratory Service Center

2. WATER (Water Analysis, Treatment and Environmental Research)
3. Soil Test Pvt. Ltd. - R, C
4. Nepal Environmental and Scientific Services (NESS) - R, C
5. Cemat
6. Environment and Public Health Organization (ENPHO) - R, C
7. Water Engineering Service - R
8. Research Laboratory for Agricultural Biotechnology and Biochemistry (RLABB)

Public Corporations

1. Nepal Water Supply and Sewerage Corporation, Central Laboratory
2. Nepal Water Supply and Sewerage Corporation, Research and Quality Control Laboratory
3. Royal Drugs Limited

Hospitals

1. Patan Hospital
2. Institute of Medicine
3. Bir Hospital
4. Central Health Laboratory

Industry

1. Himalaya Brewery Limited
2. Himal Cement Company
3. Bottlers Limited
4. Kathmandu Milk Supply Scheme

Annex 2: Recommended Equipment for Water Quality Monitoring Program

Field Equipment/Instrumentation

a) Thermometer (generally incorporated into instrumentation for Dissolved Oxygen and Conductivity).

b) Dissolved Oxygen Meter (DO kits not necessarily accurate).

c) Conductivity Meter (usually also associated with thermometer and salinity).

d) pH Meter.

e) Water quality sampling bottle (alpha bottle or similar equipment).

f) Depending upon conditions, a boat or waders may be appropriate.

Laboratory Equipment/Instrumentation

In addition to standard laboratory equipment and supplies:

a) Chemical laboratory for analysis of water samples.

b) Spectrophotometers for appropriate tests.

c) Atomic Absorption Spectrophotometer (for heavy metal analysis).

d) Biochemical Oxygen Demand and Chemical Oxygen Demand facilities.

e) Bacteriological laboratory for coliform and fecal coliform analysis.

f) Electronic balance (or equivalent).

Annex 3: Workshop Participants

Mr. Lee Wang	International Resources Group
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Mr. Sudesh K. Malla	Department of Electricity Development
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Literature Cited

Bizer, J. R. 1999. Avoiding, Minimizing, Mitigating and Compensating the Environmental Impacts of Large Dams. Prepared for IUCN - The World Conservation Union, Gland, Switzerland. 93 pp.

Bottino, A. 1988. Pollution Monitoring of the Bagmati River, Preliminary Report. FPAN-DISVI. Project

Committee on Materials for Concrete Dams. 1987. Exposure of concrete in dams to special aggressive agents. International Commission on Large Dams.

Ledec, G., J. D. Quintero, and M. C. Mejia. 1997. Good Dams and Bad Dams: Environmental and social criteria for choosing hydroelectric project sites. Sustainable Development Dissemination Note #1. Environmentally and Socially Sustainable Development Sector Management Unit, The World Bank. 22 pp.

McCartney, M. P., C. Sullivan and M. C. Acreman. 1999 (in prep). Ecosystem Impacts of Large Dams (Draft). IUCN. 75 pp.

National Planning Commission. 1998. The Ninth Plan (1997-2002). His Majesty's Government of Nepal. (Unofficial translation)