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COMPILERS	J. King, H. Sabet, C. Brown and S. Hirst
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EXECUTIVE SUMMARY

This document is the Final Summary Report of Contract LHDA 648 - *Establishment & Monitoring of the Instream Flow Requirements for River Courses Downstream of Lesotho Highlands Water Project Dams*. The client was the Lesotho Highlands Development Authority and the project was undertaken by Metsu Consultants, a joint venture of SMEC International of Australia and Southern Waters Ecological Research & Consulting of South Africa.

This report's purpose is to summarise the process, findings and recommendations of the Instream Flow Requirement (IFR) study for a wide readership of scientists, interested parties and decision makers. This summary report is a stand-alone document that draws on data given in more detail in a final report series comprising 20 technical reports, each dealing with a specific aspect of the study.

The study area comprised all the main river courses in Lesotho downstream of the structures developed or planned as part of the Lesotho Highlands Water Project (LHWP). These included the Malibamats'o River downstream of Katse Dam, the Matsoku River downstream of the Matsoku Weir, the Senqunyane River downstream of the Mohale Dam and the mid- and lower reaches of the Senqu River, which will also be affected by the proposed Mashai Dam on the Senqu River.

Establishment of IFRs in water-resource projects has a three-fold objective - to reserve some water for maintenance of ecosystems downstream of the control structure(s), to ensure the reserved water is made available to the ecosystem at the times when it is most appropriate for river maintenance, and to define water quality, physical habitat and biotic communities that characterise required river conditions.

The method employed in the LHWP IFR assessment was termed DRIFT (*Downstream Response to Imposed Flow Transformations*). This is an holistic approach in that it addresses all aspects of the river from channel form to the plants and animals. It differs from other holistic approaches developed in South Africa and Australia, both by being scenario-based, which makes it particularly amenable for use in negotiations over water, and by having an integral socio-economic module. Eight IFR sites were selected on the rivers as representative of the various river reaches. For each site, a range of summary hydrological statistics were derived, and represented on cross-section diagrams, so the links between river flow and site features, such as bank vegetation, could be understood. Field studies were conducted at each site on the biophysical components, including geomorphology, water quality, aquatic biota, riparian vegetation and riverine wildlife. The biophysical consequences of reductions in flow levels at each site were assessed by the specialists, based on the field data and on their knowledge of river-functioning, the biotic communities and/or species.

Three modified flow regimes were hypothesised, based on the design of the LHWP structures and the amounts of water they could release to downstream. An additional baseline regime was examined in which minimal degradation of downstream ecosystems with the dams in place was considered. Biophysical consequences of

each scenario (Minimum Degradation, Design Limitation, Treaty and an intermediate Fourth Scenario) were assessed by the study team, and severity of change of river condition rated on a percentage scale.

Based on a pilot socio-economic survey, the population at risk along the river reaches was defined, and resource-use data subsequently collected through a detailed survey. The social team assessed the social impacts of biophysical river changes. Public and livestock health consequences were included in the overall assessments. The values of the various resource losses and health mitigation costs were then assigned. Finally, the impacts of each scenario on overall system water yield were computed.

The scenarios allow decision makers to assess future options. In general, the more water released downstream (Table E.1), the less the change in river condition and associated socio-economic impacts to the riparian people, but conversely, the greater the impact on system yield.

Table E.1 Historical MAR, the annual volume allocated to the river and the percentage of historical MAR that this represents, under each of the four scenarios at each IFR site. Shaded sites represent reaches immediately downstream of Phase 1 and 2 dams.

IFR Site	Historical MAR	Minimum Degradation Scenario		Treaty Scenario		Design Limitation Scenario		Fourth Scenario	
	MCM a ⁻¹	MCM a ⁻¹	As % of MAR	MCM a ⁻¹	As % of MAR	MCM a ⁻¹	As % of MAR	MCM a ⁻¹	As % of MAR
1	87	51	59%	4	5%	35	40%	31	36%
2	554	366	66%	22	4%	184	33%	97	18%
3	774	436	56%	95	12%	315	41%	226	29%
4	1572	866	55%	130	8%	542	34%	288	18%
5	1924	1194	62%	486	25%	829	43%	720	37%
6	3330	2171	65%	1439	43%	1781	53%	1620	49%
7	355	231	65%	48	13%	126	35%	77	22%
8	592	397	67%	158	27%	254	43%	195	33%

A wide range of river conditions is possible in the LHWP Phase 1B development because of the availability of flexible release mechanisms at Mohale Dam and Matsoku Weir. There are fewer options for the Malibamats'o River (Phase 1A) because of the release limitations of Katse Dam. If Phase 2 were to proceed, Mashai Dam could be designed with a specific river condition in mind.

Irrespective of the releases made, the rivers will change, simply because of the presence of the dams and their effects on flow, sediment transport, and plant and animal movements.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASV	Active storage volume
CS	Critically severe
DL	Design Limitation
DRIFT	Downstream Response to Imposed Flow Transformations
ESSG	Environmental & Social Services (LHDA)
FSL	Full Supply Level
GoL	Government of Lesotho
IFA	Instream Flow Assessment
IFR	Instream Flow Requirement
LHDA	Lesotho Highlands Development Authority
LHWC	Lesotho Highlands Water Commission
LHWP	Lesotho Highlands Water Project
M	Moderate
MAR	Mean Annual Runoff
MCM	Million Cubic Meters
MD	Minimum Degradation
MOL	Minimum Operating Level
Ni	Negligible
PAR	Population at Risk
POE	Panel of [Environmental] Experts
RFP	Request for Proposal
RSA	Republic of South Africa
S	Severe
TOR	Terms of Reference
TSS	Total Suspended Solids

SECTION 1. BACKGROUND

1.1 LESOTHO HIGHLANDS WATER PROJECT

The Lesotho Highlands Water Project (LHWP) is one of the most ambitious water-diversion schemes undertaken in the world. Its prime purposes are to transfer water from the highlands of Lesotho to the Vaal River catchment in South Africa and to generate hydropower for use in the sub-region. The institution responsible for project development and management is the Lesotho Highlands Development Authority (LHDA), while the Lesotho Highlands Water Commission (LHWC, previously the Joint Permanent Technical Commission) is responsible for overseeing the provisions of the LHWP Treaty between Lesotho and South Africa.

The LHWP is being developed in four phases. Phase 1 consists of two parts (1A and 1B). The construction of Phase 1A is essentially complete, while 1B is scheduled for completion in 2003.

Phase 1A comprises:

- A 185 m high, double-curvature concrete-arch dam at Katse on the Malibamats'o River.
- An 89 m high, free-standing intake-tower located in the Katse reservoir.
- A 45 km long transfer tunnel from the Katse intake structure to the 'Muela generating station.
- A 72 mW, three-unit, underground hydraulic generating station and associated works located at 'Muela in the Nqoe Valley.
- A generating station bypass tunnel and associated works.
- A 55 m high, double-curvature arch dam located on the Nqoe River that impounds the generating station tailrace and forms the head pond for the water delivery tunnel.
- The delivery tunnel intake works at 'Muela Dam.
- A 37 km long delivery tunnel from 'Muela to the Ash River outfall in the RSA.
- Extensive supporting infrastructure.

When completed in 2003, Phase 1B will consist of:

- A 145 m high, concrete face rockfill dam at Mohale on the Senqunyane River, approximately 30 km south-west of the Katse Reservoir.
- A 32 km long, 4 m finished diameter, interconnecting tunnel from the Mohale Reservoir to the Katse Reservoir.
- The Mohale tunnel intake and outlet works.
- An approximately 19 m diversion gravity weir located 6 km east of the Katse Reservoir on the Matsoku River.
- A 6.4 km long, 3.8 m finished diameter, interconnecting tunnel from Matsoku Reservoir to the Katse Reservoir.
- The Matsoku tunnel inlet and outlet works.
- Extensive supporting infrastructure.

The next three phases of the LHWP are presently scheduled for completion by 2020. These include the Mashai Dam (Phase 2), the Tsoelike Dam (Phase 3) and the Ntoahae Dam (Phase 4) all on the mid and lower Senqu River. A fifth phase, which involves the construction of Malatsi Dam on the lower Senquyane River, has also been proposed.

1.2 TREATY ON THE LESOTHO HIGHLANDS WATER PROJECT

The LHWP is a joint undertaking by the governments of Lesotho and South Africa. Project development is guided by the Treaty on the LHWP, which was signed in 1986. The Treaty sets out important provisions for amounts of water diverted and the addressing of the effects of such water transfer and associated project development. The Treaty currently addresses only Phase 1 of the LHWP and would have to be renegotiated for Phase 2 and subsequent developments.

Article 7(9) of the Treaty refers to water released to rivers downstream of the LHWP structures, and states "*The LHDA shall at all times maintain rates of flow in the natural river channels immediately downstream of the Katse and Mohale Dams of not less than 500 and 300 litres per second respectively and shall, if so required, release the quantities of water from either Katse or Mohale reservoirs as the case may be, necessary to maintain such rates of flow: provided that subsequent to the implementation of Phase 2 of the Project, such rates of flow may be adjusted by agreement between the Parties and provided further that in the event of either reservoir being at its minimum operating level, the quantities of water released shall be equal to the flow rate into such reservoir not in excess of the specified rate of release.*" The Treaty made no provisions for releases from the Matsoku Weir.

Article 7(18) of the Treaty refers to the welfare of local people in the Project area and states "*The LHDA shall effect all measures to ensure that members of the local communities in the Kingdom of Lesotho, who will be affected by flooding, construction works or similar project-related causes, will be able to maintain a standard of living not inferior to that obtained at the time of first disturbance: provided that such Authority shall effect compensation for any loss to such member as a result of such project-related causes not adequately met by such measures.*"

Article 15 of the Treaty addresses similar concerns and states "*The Parties agree to take all reasonable measures to ensure that the implementation, operation and maintenance of the Project are compatible with the protection of the existing quality of the environment and, in particular, shall pay due regard to the maintenance of the welfare of persons and communities immediately affected by the project.*"

1.3 WATER TRANSFERS AND RIVER FLOWS

Phase 1 of the LHWP was designed to maximise the amount of water that would be transferred from Lesotho to the RSA, and only minimal amounts were to be released through the structures to the downstream river channels. The Treaty-defined releases (termed 'compensation flows' at that time) through Katse and Mohale Dams of 0.5 and 0.3 m³ s⁻¹, represented values, for the Malibamats'o and Senquyane Rivers respectively, which exceeded annual minimum flows in nine out of every ten years of record. The ecological basis, if any, for these selected values was not stated. Earlier environmental evaluations considered that negative impacts would be mainly limited to the proximal reaches of downstream rivers and would be mitigated by flows from (unregulated)

downstream tributaries. The Treaty releases represent about 2.6% of the overall long-term yield of the Malibamats'o and Senqunyane Rivers (measured at the sites of the respective dams).

The need to determine more realistic and defensible releases to downstream rivers was identified in 1994 when the Phase 1B environmental impact assessment was initiated. The World Bank emphasised the importance of determining instream flow requirements (IFR) on a scientifically justifiable basis, while international NGOs identified the absence of instream flow assessments as a weakness in LHWP planning. Estimation of IFRs for the lower Matsoku River became a key concern in project justification in late 1996.

1.4 DETERMINATION OF INSTREAM FLOW REQUIREMENTS

Metsu Consultants, a joint venture between SMEC international of Australia and Southern Waters of South Africa, was awarded a contract (LHDA 648) by the LHDA in 1997 to undertake a detailed assessment of the IFRs of the river reaches downstream of the LHWP structures. The study addressed the Malibamats'o River downstream of Katse Dam, the Senqunyane River downstream of Mohale Dam, the Matsoku River downstream of the Matsoku Weir, and the Senqu River downstream of the Malibamats'o confluence (potentially affected by all Phase 1 structures plus any future phase dams). The Nqoe River (Muela Dam) was excluded from the scope of the study, which was also geographically restricted to Lesotho. The study was required to assess the long-term impacts of modified flow regimes on the ecosystems and communities of the study rivers, provide recommendations for mitigation and compensation, and recommend a long-term monitoring programme. In advising the LHDA on the costs or benefits of providing adequate IFRs, economic evaluations were to be limited to local and regional economies (i.e., not deal with the economic consequences of changes in water deliveries to RSA).

Annex A lists details of the Project Study Team and the various sponsoring and co-operating institutions. Annex B contains the terms of reference under which the study was conducted, while Annex C presents details of the method employed.

1.5 PURPOSE OF THIS REPORT

This document is the Final Report of Contract LHDA 648. Its purpose is to summarise the process, findings and recommendations of the IFR study. This report is supported by a final report series comprising 21 technical reports, each dealing with a specific aspect of the study and each of which is comprehensively cross-referenced. A list of reports in the final report series is presented in Annex D. All bibliographic references are contained in the technical reports and have not been repeated in this summary report for the sake of brevity of presentation.

SECTION 2. NATURE OF INSTREAM FLOW ASSESSMENTS

2.1 INSTREAM FLOW ASSESSMENTS AS A RESPONSE TO RIVER REGULATION

An Instream Flow Requirements (IFR) is a description of a modified flow regime for a river, which is linked to a description of the condition or health of the river that this flow achieves.

The flow regime of a river consists of several different kinds of flow, each of which contributes to the overall maintenance of the aquatic ecosystem.

- *Low flows* are the normal flows in a river outside of floods. In most cases these flows establish the basic perennial nature of the rivers and hence the animals and plants that inhabit them. The different magnitudes of low flow in the dry and wet seasons create more or less wetted habitat and different hydraulic and chemical conditions, which directly influences the balance of species.
- *Large floods* occur less than once a year. They dictate the general geomorphological character, shape and size of a river channel. Floods mobilise sediments and deposit silt, nutrients and seeds on floodplains. They inundate backwater areas, and can trigger the emergence of adults of aquatic insects, which provide food for fish, frogs and birds. They maintain soil moisture levels in the banks that support the trees and shrubs, and the periodic disturbances created by these floods prevent riparian vegetation from being dominated by any one species.
- *Small floods* occur several times within a year. They stimulate spawning in fish, flush out poor quality water, mobilise sandy sediments, and contribute to flow variability. They re-set a wide spectrum of conditions in the river, triggering and synchronising activities as varied as upstream migration of fish and germination of riparian seedlings.
- *Flow variability*, on a daily, seasonal or annual basis, acts as a form of natural disturbance. Variability is an important factor in river ecosystem functioning as it maintains biological diversity through increasing environmental heterogeneity. Rivers with diverse communities of plants and animals are usually regarded as more healthy and resilient, and thus less vulnerable to disturbance, than ones with low diversities.

Manipulations of flow regimes represent unnatural disturbances to aquatic ecosystems. These disturbances increase in severity as flow regimes are altered from what lies within the realm of "normal" for the particular systems. Responses of the ecosystem become more extreme as disturbance increases, and can take many forms. For instance, hydrological cues that trigger fish spawning or seed germination may occur at the wrong time of the year or not at all, resulting in affected species perhaps failing to reproduce. Seasonal reversal of wet and dry season low flows could mean that hydraulic and thermal conditions become mismatched with life-cycle requirements, again causing species to decrease in numbers and abundance. Other species, including those regarded as pests, are able to take advantage of such environmental conditions, or the weakening of competition from the affected species, and increase in abundance.

2.2 PURPOSE OF IFR DETERMINATION

IFRs are established to mitigate the potential impacts of river flow reductions on aquatic ecosystems in three ways.

- *By reserving some water for ecosystem maintenance* - in general, the closer to natural the desired condition, the greater the volume of the original flow regime required for the IFR.
- By ensuring that the reserved water is made available to the ecosystem at the times when it is most appropriate for river maintenance - for instance, if large floods are needed in a river to maintain beaches and backwaters, or small floods to stimulate fish spawning, then the IFR would stipulate the magnitude, duration, timing and frequency of the required floods.
- *By defining water quality, physical habitat and biotic communities that characterise specific river conditions* - in this manner, the IFR is linked to measurable goals that can be used to assess whether the desired river condition is being achieved.

Even the most successful IFR would only partially mitigate the effects of a water-resource development as the presence of a dam would, in itself, inevitably result in downstream impacts. Application of an IFR moreover cannot guarantee a desired condition in a river since other activities in the catchment also affect river condition. For instance, even if the IFR is implemented correctly, pollution from industry or agriculture could result in unacceptable water quality in the river. Thus, an IFR should be established and implemented as part of a catchment management plan that has as part of its objectives maintaining the desired condition of the river.

2.3 METHOD DEVELOPMENT

Methods for determining an IFR for regulated rivers and streams have been in use in North America for the past 50 years and have been used increasingly in South Africa for the past two decades. The present study represents their first application in Lesotho. Earlier methods, used elsewhere, applied statistical analysis of historic hydrological data to determine minimum flows for fisheries or other specified ecological features. Subsequent methods placed emphasis on hydraulic rating assessments. Habitat simulation, mostly for fish, as a way to establish IFRs is in widespread use in some countries, has been used to a limited extent in South Africa, and is best represented by the Instream Flow Incremental Methodology (IFIM) and its many derivatives.

More holistic approaches to determining IFRs have been advocated in South Africa and Australia, typified by the development of the *Building Block Methodology* (BBM) in the former country and the *Holistic Approach* in the latter. These methods consider various components of whole river systems when advising on environmental flows. Full descriptions of these methodologies were provided in the study (Report No. 648-F-03).

In consultation with the LHDA and the POE, the Consultant decided that an holistic approach to the LHWP IFR was justified, and the method applied should:

- allow the flow requirements to be assessed for all major components of the riverine ecosystem (e.g., riparian vegetation; channel form);
- assess the flow requirements for several rivers;
- address both water quality and quantity requirements for the rivers;

- allow several potential flow regimes to be described, each with its predicted consequences (i.e., a scenario-based approach);
- incorporate a comprehensive and structured socio-economic component.

The initial approach used in the study was based on the BBM. However, to meet the specific requirements of the study area and the biophysical conditions and constraints, a new approach was developed during the study and was termed DRIFT (Downstream Response to Imposed Flow Transformations). Using the present-day flow regime of the river as a starting point, this was used to:

- carry out a preliminary characterisation of the rivers and select eight representative IFR sites on the basis of geomorphology, proximity to gauging stations and general accessibility;
- describe the various biophysical consequences for the rivers of further reducing (or, if relevant, of increasing) the flow in a number of different ways;
- create a database of these biophysical consequences, each linked to its flow-reduction details;
- create a range of potential modified flow regimes by combining the various flow reductions in a variety of ways;
- query the database to predict the outcome of these modified flow regimes in terms of river condition (i.e., the relevant biophysical consequences);
- spatially and functionally identify the human communities dependent on the river and its resources (termed the Population at Risk – PAR);
- link the biophysical consequences of river changes to health, cultural and economic issues related to the riparian people; and
- calculate the economic costs of mitigation and compensation for the loss of river resources and services used by these people.

A step-wise description of the DRIFT method is given in Annex C.

2.4 UNCERTAINTY AND ADAPTIVE MANAGEMENT

Establishment of IFRs is seldom an exact science because of the complex and poorly understood functioning of river ecosystems. This was especially true for the extensive and poorly studied rivers in the LHWP areas. A measure of uncertainty was inherent in the reported predictions of flow requirements and the consequent levels of resource loss and socio-economic impacts associated with flow alteration and reduction. In this study, uncertainty was addressed through the use of a method that emphasised interactions between specialists to maximise information sharing, and the assigning of ranges of likelihood of occurrence rather than specific values by specialists. However, the most effective way of dealing with uncertainty will be the gradual confirmations, refutations and/or adjustments made possible by the collection and feedback of specific information from the monitoring programme in an organised system of adaptive management.

SECTION 3. STUDY AREA

3.1 CHARACTERISTICS OF THE STUDY AREA

Lesotho is a land-locked country, 30,355 km² in extent. The eastern two-thirds are dominated by the rugged Drakensberg and Maloti ranges, which form a high dissected plateau with an average elevation of about 3100 masl. The region lies within the Great Karoo Basin of southern Africa and is characterised by early sedimentary rocks overlain by basaltic lavas. The narrow river valleys are steep-sided and the landscape exhibits high to very high relief. The soils at higher elevation are derived from basalt, are generally thin at high elevations and on steep slopes, and are deeper in the valley bottoms. Lowland soils are derived from sandstone. The Senqu (Orange) River drains the eastern and southern sectors and has several large tributaries including the Malibamatso, Senqunyane and Matsoku rivers, which are the location for the Lesotho Highlands Water Project (Figure 3.1).

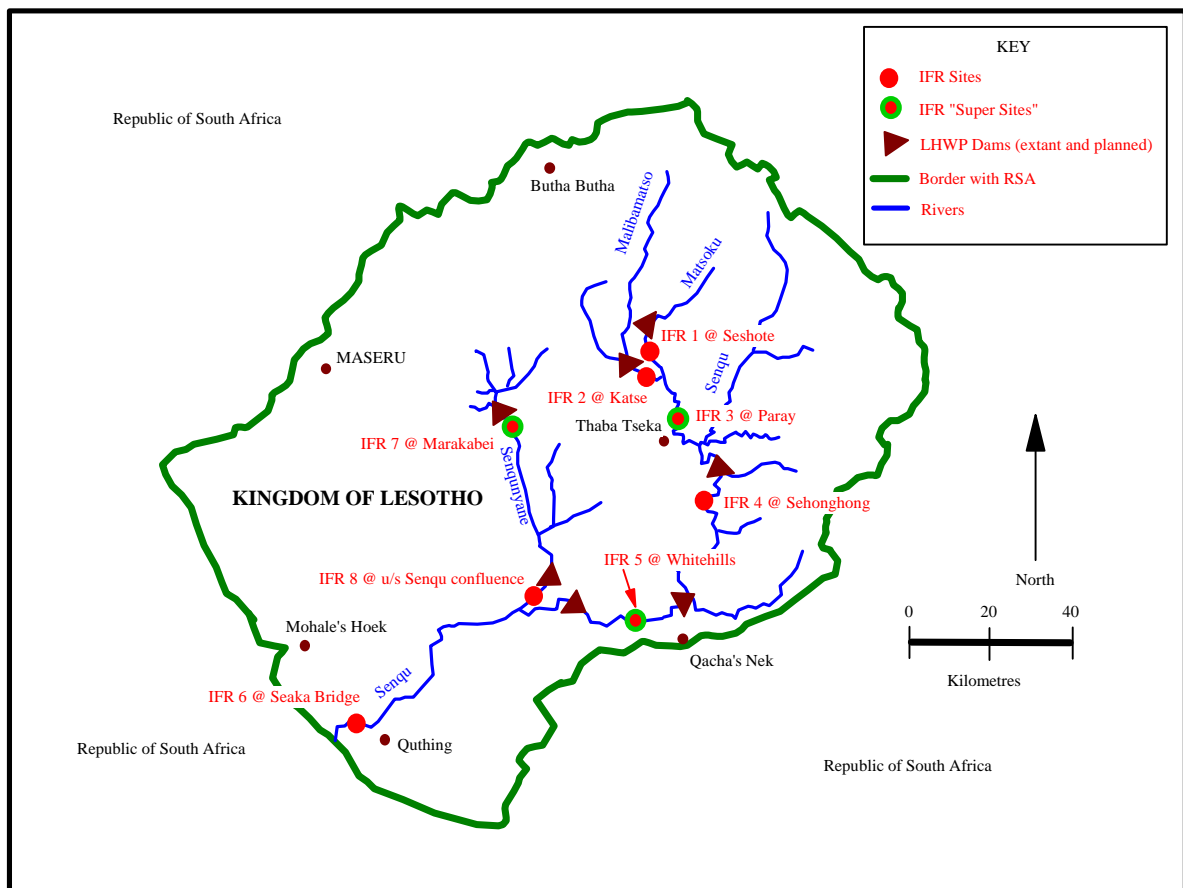


Figure 3.1 Location of the study rivers and IFR sites.

Highland catchments are characterised by high rainfall, temperate summers and long cold winters, and have high water yields due to rapid runoff from the steep slopes. Rainfall occurs predominantly as thunderstorms and is of high intensity and short duration. The nature of the rainfall and the rapid movement of water off the steep slopes and thin soil results in a quick drainage reaction time in relation to surface runoff. Highly variable but distinct wet, dry and transitional seasons are identifiable from hydrological records. The wet/rainy season extends from December to March, while the dry season usually extends from June through September.

Grasslands and shrublands with occasional wetlands dominate the highland vegetation. Vegetation zones along the rivers typically have a higher biodiversity than elsewhere and a higher proportion of woody vegetation consisting of both indigenous and exotic species. Wildlife communities of Lesotho are highly distinctive with several endemic species, but wildlife densities are very low due to heavy uncontrolled exploitation.

The human population along the rivers downstream of the LHWP structures is about 155,000. Most of these people live in small villages, with a small proportion living in larger settlements such as Marakabei. Lack of formal education and high unemployment are characteristic of most communities. Rural people are heavily dependent on local resources for their livelihood, while foreign employment (South African mines) represents an important but declining source of income. Agriculture is an important source of livelihood but agricultural lands are constrained in size by topography and soil depths. Relatively more and better land is available along the Matsoku and upper Senquyane rivers than along the deeply incised Malibamats'o and upper Senqu rivers. Livestock are abundant in the study area (estimated populations of 68,000 cattle, 78,000 sheep, 131,000 goats and 24,000 horses and donkeys). Nutritional levels of local people, especially children, are poor, even by Lesotho rural standards, and there is a high incidence of childhood infectious diseases as well as water-borne and water-washed diseases.

3.2 STUDY SITES

Within the broad study area, the areas addressed were delineated according to the needs of the social and biophysical portions of the study.

3.2.1 River Reaches

The following reaches comprised the main area for the IFR determination:

- Malibamats'o River downstream of the Katse Dam (LHWP Phase 1A) to the confluence with the Senqu River.
- Matsoku River downstream of the proposed diversion weir (LHWP Phase 1B) to the confluence with the Malibamats'o River.
- Senqu River from the confluence with the Malibamats'o River to the Lesotho/RSA border.
- Senquyane River downstream of the Mohale Dam (LHWP Phase 1B) to the confluence with the Senqu River.

3.2.2 Definitions

The following definitions were applied.

IFR Sites: sites for the collection of biophysical data; IFR sites were c. 1 km long sections of rivers that were considered representative of the river reach on which they were situated; IFR sites extended to the 1:100 year flood line on either side of the river; sites were selected on the basis of typical geomorphology, flow characteristics, riparian vegetation, proximity to a flow or water level gauging station, and proximity to road access.

IFR Reaches: lengths of river represented by each IFR site; reaches were defined by the locations of major confluences, geomorphology and degrees of habitat integrity.

Social Villages: units for the collection of sociological data; survey data were in fact collected at the level of the household, while the villages defined the geographical cover afforded by the social study.

Clinics: units for the collection of public health data.

Social Reaches: the same stretches of river as the IFR reaches, each representing nearby social village/s.

3.2.3 IFR Sites and Reaches

- IFR Site 1 On the Matsoku River near the village of Seshote (29°15'21"S, 28°33'51"E), representing the Matsoku River from the site of the proposed Matsoku Weir to the confluence with the Malibamats'o River (IFR Reach 1);
- IFR Site 2 On the Malibamats'o River downstream of the Katse Bridge (29°21'08"S, 28°31'32"E), representing the Malibamats'o River from Katse Bridge to the confluence with the Matsoku River (IFR Reach 2);
- IFR Site 3 On the Malibamats'o River at Paray (29°29'52"S, 28°39'04"E), representing the Malibamats'o River from the confluence with the Matsoku River to the confluence with the Senqu River (IFR Reach 3);
- IFR Site 4 On the Senqu River at Sehonghong (29°44'20"S, 28°45'19"E), representing the Senqu River from the confluence with the Malibamats'o River to the confluence with the Tsoelike River (IFR Reach 4);
- IFR Site 5 On the Senqu River at Whitehills (30°03'56"S, 28°24'28"E), representing the Senqu River from the confluence with the Tsoelike River to the confluence with the Senqunyane River (IFR Reach 5);
- IFR Site 6 On the Senqu River at Seaka Bridge (30°21'48"S, 28°11'30"E), representing the Senqu River from the confluence with the Senqunyane River to the Lesotho/South Africa border (IFR Reach 6);
- IFR Site 7 On the Senqunyane River at Marakabei (29°32'09"S, 28°09'15"E), representing the Senqunyane River from the site of the proposed Mohale Dam to the confluence with the Lesobeng River (IFR Reach 7);
- IFR Site 8 On the Senqunyane River upstream of the confluence with the Senqu River (30°02'11"S, 28°13'21"E), representing the Senqunyane River from the confluence with the Lesobeng River to the confluence with the Senqu River (IFR Reach 8).

3.2.4 Social Villages and Reaches

The socio-economic study comprised three inter-linked data collection exercises, namely:

- a pilot sociological and anthropological survey of eight villages (Report No. 648-F-08);
- a detailed survey consisting of 1,680 household interviews, distributed over 32 clusters, each representing one of the eight IFR river reaches;
- an assessment of the records of nine clinics and one hospital (Report No. 648-F-09).

3.2.5 Pilot Sociological Survey

Eight villages were surveyed in the pilot sociological survey.

- Ha Soai at the confluence of the Matsoku and Malibamats'o Rivers.
- Koma-Koma village on the Senqu River (north).
- Ha Noha village (Marakabei) and Ha Motenalapi village (Semonkong) on the Senqunyane River.
- Auplaas village, Ha Sekake, Ha Koali village (Mt Moorosi) and Ha Ramatlalla village (Alwynskop) on the Senqu River (south).

3.2.6 Detailed Sociological Study

The social reaches were the same as the IFR reaches (Section 3.1). On the basis of the results of the Pilot Sociological Survey (Section 3.2.5), a corridor 5 km wide either side of the river (i.e., a total width of 10 km) was demarcated for each river reach and randomly selected villages within this corridor were visited.

3.2.7 Clinics

Ten clinics were used in the public health survey.

- Seshote Clinic (near IFR 1).
- Khohlontso Clinic (near IFR 2).
- Paray Hospital (near IFR 3).
- Mohlanapeng Clinic and Sehonghong Clinic (near IFR 4).
- Sekake Clinic (near IFR 5).
- Mount Moorosi Clinic, Phamong Clinic, Holy Cross Clinic (near IFR 6 and 8).
- Marakabei Clinic (near IFR 7).

3.2.8 Location of IFR Sites in Relation to Gauging Stations

The location of reliable hydrological gauging stations was a very important consideration in establishing the location of the biophysical and social study sites, since the biophysical data had to be linked to flow in the rivers. Table 3.1 provides a list of the hydrological gauging sites that were used along with an indication of the reliability of the data from each weir and the biophysical IFR sites to which they were linked.

Table 3.1 Gauging weirs located near to IFR sites, and an indication of the quality of the data obtainable from each weir.

Site	Gauging Station No.	Reliability of Data
IFR 1	G42 (Seshote)	Fair
IFR 2	G41 (Bokong) and Katse Dam	Poor
IFR 3	G08 (Paray)	Fair
IFR 4	G05 (Koma-koma)	Fair
IFR 5	G04 (Whitehills)	Fair
IFR 6	G03 (Seaka)	Fair-poor
IFR 7	G17 (Marakabei)	Fair
IFR 8	G32 (Nkaus)	Very poor

3.3 SUMMARY OF THE AVAILABLE HYDROLOGICAL DATA

Detailed hydrological analyses of all IFR sites were performed using the historical hydrological data for the period 1930-1995. These included:

- synthesis and presentation of historical flows at all IFR sites, giving annual variability, monthly variability, daily variability, frequency and duration of high and low flows;
- synthesis and presentation of present flow data (Katse Dam in place) giving all the above parameters;
- synthesis and presentation of future data with Treaty releases from Phase 1 and 2 facilities in place;
- flood-frequency analysis using partial and annual series; and
- hydrological analysis of daily stream flow data for historical, present and future (Phase 1 and Phase 2 dams in place) conditions for input to the DRIFT process.

Details of these analyses are presented in the Hydrology Report No. 648-F-13.

SECTION 4. APPLICATION OF THE DRIFT METHOD TO THE LHWP

Ideally any IFR methodology, including DRIFT, should be applied in the feasibility and/or early design phases of a project to permit maximum use of the information and full interchange of information between the engineering design and downstream environmental and socio-economic assessments. This was not possible with the current project since Katse Dam was completed by the time the IFR assessment commenced. Mohale and Matsoku projects were also in an advanced state of design and partial construction, with severe scheduling and cost constraints on possible design changes to accommodate flow-release modifications. Annex E summarises the designs of the outlet facilities for Phase I projects. The Treaty on the LHWP is very specific with regard to flow releases from Phase 1 projects, and any changes to accommodate IFRs would necessitate bilateral deliberations and decision-making at a high level. Furthermore, the assumed yields from Phase 1 with the Treaty flows in operation have been applied extensively in water-resource and supply planning in South Africa, and yield changes due to IFRs would have significant planning and economic repercussions.

In consultation with the client and the engineering consultants for Phase 1B, it was decided to assess IFRs through the use of scenarios which would reflect various approaches and options for flow releases and which would combine groups of biophysical and social factors to reduce the number of biophysical and socio-economic assessments to a workable number. All the scenarios assumed that Phase 1 and 2 developments (Katse, Mohale and Mashai Dams and Matsoku Weir) were in place.

4.1 SCENARIOS

Four scenarios were developed in order to determine IFRs according to DRIFT.

4.1.1 Minimum Degradation

This was a hypothetical condition in which maintenance of the rivers in a state of minimal degradation from their current condition, with the dams in place, was the main objective, and any water in excess of that required to attain this condition would be available for use elsewhere (i.e., for diversion). This scenario served the purpose of allowing decision makers to understand the best possible river condition that could be achieved with a dam in place, if the only consideration was to maintain that condition (clearly this would negate the whole purpose of the dam). It also allowed specialists to interactively consider baseline conditions relative to flow regimes and to establish the flows below which significant ecological and physical changes could be anticipated. A full description of this assessment appears in Report No. 648-F-04.

4.1.2 Treaty

This was the scenario generated by application of the release conditions mentioned in the Treaty and was at the opposite end of the range from Minimum Degradation in terms of water requirements. Conceptually the scenario differed from 4.1.1 above in that the volumes of abstracted water were first specified and consequential river conditions were then assessed. A full description of this assessment appears in Report No. 648-F-05.

4.1.3 Design Limitation

This was a scenario based on the practical limitations of flow releases imposed by the designs of the Phase 1 structures and by a requirement for moderate yield from the scheme (Annex E). In terms of volumes of water, the releases required are intermediate between the above scenarios. A full description appears in Report No. 648-F-06.

4.1.4 Fourth Scenario

This scenario was selected to fall midway between the Treaty and Design Limitation Scenarios and to provide a reference point between the former (legally defined and highest water yield but most severe environmental and socio-economic impacts) and the latter (possible within engineering constraints but likely to have high impacts on water yield and overall costs). This scenario is fully described in Report No. 648-F-07.

4.2 DESIGNATION OF SEVERITY RATINGS USED FOR BIOPHYSICAL CONSEQUENCES

4.2.1 Individual Component Responses to Specific Flow Releases

For each biophysical component at each flow reduction, the level of severity of the consequences for each of its sub-components was assessed relative to the present day condition of the river. A rating scale from 0 (no change) to 5 (critically severe change) was used to express the severity of change.

Uncertainty was expressed in two ways:

- The severity ratings themselves referred to a percentage *range*, e.g., a severity rating of 3 might represent a percentage change of between 25-50%.
- If the level of uncertainty for a predicted change was greater than noted above, then a range of severity ratings was specified by the respective specialist(s).

4.2.2 Ecosystem Responses to Overall Reduced Flow Releases

The set of biophysical consequences and explanations linked to each flow reduction level within a scenario were assessed in combination to create a description of an overall ecosystem response for each river reach within each scenario. These are summarised further in Sections 5 to 8. The levels of impact can be interpreted as changes in the river from present-day (near natural) conditions, or for IFR Site 2 (immediately downstream of Katse Dam) from an estimated near-natural condition, as follows:

None: The river will stay in approximately the same condition as at present.

Negligible: 0-10% change in most subcomponents, or most important subcomponents, of the riverine ecosystem.

Low: 10-20% change.

Moderate: 20-40% change.

Severe: 40-80% change.

Critically severe: 80≥100% or more change.

4.3 DESIGNATION OF SEVERITY RATINGS USED FOR SOCIO-ECONOMIC CONSEQUENCES

The social impacts were assessed on a scenario-specific basis, i.e., the method required the identification of a comprehensive modified flow regime and its biophysical consequences *before* its social impacts could be determined.

4.3.1 Cultural and Subsistence Use of River Resources

The impacts on cultural and subsistence use of river resources were assessed using the predicted biophysical changes, the critical nature of the usage (i.e., the importance of the resource for the livelihoods of the affected populations), the number of households harvesting the resource, the frequency of usage, and the availability of alternative resources. The resulting social impact was then ranked for each resource on a four-point scale, using expert opinion, as follows:

- None: No appreciable change expected.
- Low: The resource is not important or, if important, its quantity is predicted to change by < 20%.
- Moderate: The resource is important, and its quantity is predicted to change by 20-50%.
- Severe: The predicted biophysical change is > 50%, the resource is considered to be essential for the livelihoods of the affected populations.

4.3.2 Public and Animal Health

The impacts on public and animal health were assessed using the biophysical changes that could influence people's health, the wide range of factors influencing health and data on the extent of river use by members the PAR and their livestock. In Lesotho most of the diseases considered already occurred in the country and there was a risk of contracting them even in the absence of the LHWP. Thus, for health, both a baseline probability and a future probability of contracting a disease or facing a health risk were assessed using the following scale:

- Negligible: 0% probability.
- Minimal/Low: 1-20% probability.
- Moderate: 21-40% probability.
- Severe: 41-80% probability.
- Critically severe: 81-100% probability.

The predicted future probability was inclusive of the baseline probability of contracting the disease. If the dams were expected to make a difference, the baseline probability was increased to reflect this. Thus, the future probability incorporates the (existing) baseline probability.

4.4 ONSET AND DURATION OF BIOPHYSICAL IMPACTS

Predicted biophysical changes would take place over a range of time scales. Some impacts, once they had occurred, would change little thereafter, e.g., geomorphological changes, whereas others would likely be cyclical, e.g., the appearance of algal blooms. However, although the predicted (and reported) consequences represented the expected average condition of the rivers in the middle-term, there could be declines into a poorer condition at times of climatic or other stress. There could also be risks of the river condition fluctuating between extreme conditions. Table 4.1 summarises the most likely timing of the biophysical impacts identified in the study.

Table 4.1 The anticipated onset, reversibility and possible periodicity of biophysical impacts.

Component	Sub-Component	Onset
Geomorphology	Changes in wetted habitat area and to the shape and complexity of the low flow channel	Immediate
	Biofilm growth on the surfaces of boulders, cobbles and gravels	1-2 years
	Colloidal sediment (clay) deposition	2-10 years
	Quantity of fine sediments in the system, e.g., mud	2-10 years
	Transport of sand -sized material	2-10 years
	Quantity of sand in the system	2-10 years
	Pool depth and number	2-10 years
	Movement of gravel/cobbles/boulders	2-10 years
	Riffle sedimentation (over time)	2-10 years
	Frequency of inundation of upper bar surfaces	2-10 years
	Flows which flush fine sediments from bar surfaces	2-10 years
	Frequency of bankfull flows	2-10 years
	Flood plain inundation	>10 years
	Frequency of inundation of bench surfaces	2-10 years
<p>Reversibility: many predicted changes would have little impact in isolation but in combination they would result in major and probably semi-permanent changes to channel shape and habitat availability. Sediments settling into a pool would, over time, become compacted so that flows that could remove them in the past would no longer be able to do so. Once the changes had occurred and conditions had become well established, then the system would only be reset by an unusually large flood event, e.g., a 1:100 year flood.</p>		
Water Quality	Nutrient and TSS variability	1-2 years
	Nutrient and TSS magnitude	1-2 years
	Nutrient and TSS mobilisation	1-2 years
	Temperature – increase in daily variation	Immediate
	Rapid-Bio-Assessment	1-2 years
	Dissolved Oxygen – chance of anoxic conditions	1-2 years
<p>Reversibility: assuming there are no major changes in land use, the water quality impacts would be reversible.</p>		
Vegetation	Aquatic zone: algae	1-2 years
	Aquatic zone: macrophytes	1-2 years
	Wetbank annuals	1-2 years
	Wetbank sedges and grasses	1-2 years
	Wetbank shrubs and trees (<i>Salix</i> zone)	2-10 years
	Drybank: tree/shrub zone	2-10 years
	Drybank: lower dynamic	2-10 years
	Drybank: back dynamic	2-10 years
	Debris deposition	2-10 years
	Dry bank: annuals	1-2 years
	Increase in potential for encroachment of exotic vegetation	2-10 years
<p>Reversibility: Except for the changes in annuals, the vegetation changes are expected to take place over a fairly long period. There would be a gradual dying off of species in sites that are no longer suitable. This would be accompanied by a shift to newly suitable areas (e.g., zones would move down towards the water's edge), so that in time the vegetation zones would be reset. However, the zones are likely to be narrower than they were previously and many of the riparian species would be less abundant. Once the changes have occurred and had a chance to settle, then the system would only be reset by an unusually large flood event, e.g., the 1:100 year flood. Algal responses would be cyclical, probably in summer; predictions indicate that algal blooms would occur more frequently than before.</p>		

Table 4.1 The anticipated onset, reversibility and possible periodicity of biophysical impacts.

Component	Sub-Component	Onset
Macroinvertebrates	General deposit and algal feeding invertebrate community	1-2 years
	Subtle changes in filter feeding community and associated other species.	1-2 years
	Overall abundance of general filter feeding invertebrates	1-2 years
	<i>Simulium</i> sp.	1-2 years
	Potential disease carrying snails, such as Planorbidae and Physidae.	1-2 years
<u>Reversibility:</u> generally reversible over a 1-10 year period if favourable conditions are restored.		
Fish	All species	2-10 years
<u>Reversible:</u> provided some individuals remained in the system (e.g., in the tributaries) then recolonisation would occur once favourable conditions were re-established. This would assume that the required habitats were also re-established (see Geomorphology). If a species was lost, the change would be irreversible unless the opportunity existed for translocations from an unaffected site.		
Amphibia		2-10
<u>Reversibility:</u> If species lost, irreversible without translocations from an unaffected site.		
Mammals And Birds		2-10, some >10 years
<u>Reversibility:</u> Reversible unless local extinctions occurred.		

4.5 COMPUTATION OF LOSSES AND COSTS

4.5.1 Resource Losses

Resource-loss estimates were based on the percentage changes predicted by the biophysical studies and the monetary value of river resources provided by the social impact studies. An important assumption with respect to the economic calculations was that, with the exception of sand, the supply of the resources was assumed to be limited and that more of the supply would be used, if it had been available. Thus, a reduction in the abundance of a resource was related linearly to a reduction in the use of that resource.

Evidence for this limitation of resources in the study area was available from the socio-economic surveys (Report Nos. 648-F-21 and 22). The communities bordering the downstream river reaches were noted to be poor, even by Lesotho standards, and are heavily dependent on local resources for food and fibre. Shrubs, trees, grazing forage, wild vegetables, herbs, reeds, thatch grass and even land within the riparian zones are considered as 'controlled resources' by the local communities, meaning that their collection and use is under the jurisdiction of the local chief, and normally only persons resident within a village have the right of access to them. Resource limitation is the main reason for the designation of such 'control'. Depletion of resources such as grazing forage, and trees and shrubs for firewood is much in evidence in the study area, as it is in most parts of rural Lesotho. By contrast, river water, sand and fish are not viewed as 'controlled' by communities since they are considered to be abundant enough for all to share. There was no evident correlation between annual fish harvests per river reach (reported by the social team) and the relative abundance of the same species at each IFR study site (reported by the ichthyofauna team) as would be expected if resource abundance was a limitation on fish harvests. However, it would have to be borne in mind that local fishermen are limited in mobility, and a loss of the fish resource in one

reach could not simply be replaced by the fishermen moving to the next reach since it might be many kilometres from their home villages.

It was considered that, as resources declined in abundance, use of them might well cease before they had entirely disappeared because of increasingly poor returns from the harvesting effort. Resource losses were therefore computed at two levels, one for a simple reduction in availability, and one applying an assumed 50% threshold below which the resource was deemed to be effectively lost. The assumption was that any resource that had a baseline mean reduction of 50 % or more could be treated as if its abundance had fallen by 100%.

The percentage reductions in the biophysical assessment of abundance of riverine resources were given as ranges. To incorporate this information into the estimation, a risk analysis was used and a probabilistic cost distribution was provided, characterised by the mean, minimum and maximum values and standard deviations. This information is given in Report No. 648-F-22.

4.5.2 Mitigation Costs

For health-related issues, the cost of compensation for loss of life or loss of health was deemed not to be calculable. Only the costs of mitigation (or prevention) of the predicted increases in diseases were calculated. Mitigation costs were based on required actions such as immunisation of children, construction of ventilated improved pit latrines, and education that dealt with the health risks associated with unsafe sanitation and/or drinking from the river. Total mitigation costs were initially calculated and then adjusted to reflect the *increase* in the health risks for the particular scenario over the baseline conditions (i.e., future minus baseline probability).

4.5.3 Compensation Delivery Costs

Within the framework of the compensation policy developed for the LHWP and applied thus far essentially in the upstream (reservoir inundation) areas, replacement of lost resources has been dominated by a replacement-in-kind approach, such as land for land or houses for houses. Even cash, when offered as compensation, is calculated on a replacement of resources or resource-use basis. The costs of replacing lost resources (i.e., the costs of delivering compensation) to communities in the downstream areas would in virtually all cases be more than the actual resource losses computed in 4.5.1 above because of remoteness of much of the area, lack of easy road access, and lack of effective supply conduits (e.g., grocery stores, timber stores) to supply the replacements. Compensation delivery costs would have to be computed by reference to resource management programmes currently ongoing in the upstream LHWP areas for assisting and encouraging communities to manage basic resources such as woodlots and subsistence fisheries.

4.6 BENEFITS OF DOWNSTREAM FLOW REDUCTION

Not all biophysical consequences of flow-regime alteration by the LHWP would be negative to downstream ecosystems and the communities living near the rivers. Report 648-F-22 notes the following potential benefits of downstream river flow reduction.

- Easier crossing of river(s) by boats and pedestrians.

- Increases in abundance and distribution of some useful plants, notably leloli (*Cyperus marginatus*), reeds (*Phragmites australis*) and thatch grass (*Hyparrhenia hirta*).

While benefits accruing to communities from a project would normally be factored into compensation programmes, this has not been done in the present study as explained below. It would be necessary to bear these potential, but unquantified, benefits in mind when establishing specific compensation programmes.

Easier crossing of the rivers represents a real but slight benefit to villagers. Because of the 'flashy' nature of the rivers in the study area and the carefully chosen locations of traditional paths and river crossings, rivers seldom impede pedestrians for periods longer than a day or two and thus do not represent a measurable impact to rural people.

Flood protection is a common benefit to people living downstream of large dams and diversions, but is considered of limited benefit in the case of the LHWP since flooding impacts are so small because of the steeply incised nature of the river valleys and the locations of most villages well above maximum flood levels. No local resident was recorded during the social surveys as mentioning flooding as a significant impact. The LHWP structures consequently represent no additional benefit and may, in fact, represent a very small but definite threat in terms of possible future dam failure.

Increases in reeds, thatch grass and leloli may well represent benefits to downstream communities but the actual extent of the benefits is difficult to quantify without long-term field studies. Whereas losses of vegetation and plant species have been measured by relating present measured abundance to a reduction in surveyed surface area presently occupied by the vegetation or plant species in question, an increase in a species would be due to an ecological process of plant succession and invasion into remaining riverine habitats which cannot easily be predicted or quantified in advance.

4.7 SYSTEM YIELD ANALYSES

Estimates of the water yields of Phases 1 and 2 under the four scenarios were carried out using the historical inflow series for the period 1930-1994 based on reviewed hydrologic data produced by the LHDA/DWAF Joint Study in 1996. An annual reliability figure of 98% was used (i.e., a risk of failing to deliver the stated yields in two years within every 100-year span). A particular set of water releases was assumed, according to the prescriptions for the relevant scenario, the constraints imposed by the release facilities (see Annex E), and the capacities of the Mohale and Matsoku diversion tunnels and the Mashai-to-Katse pumping plant. Yield estimates were based on the IFRs required at sites immediately downstream of the Phase 1 and 2 structures for each of the four scenarios, since these requirements had the major effect on system yields. It was found that IFRs for sites located far downstream of the structures did not greatly affect overall system yields.

Table 4.2 summarises the input parameters used in the modelling of the Phase 1 and 2 yields. Further details are given in Report No. 648-F-20.

Table 4.2 Summary of input parameters used in Phases 1 and 2 yield analysis. MCM = million cubic meters; ASV = active storage volume.

Item	Unit	Value
Annual Reliability of Supply	%	98.0
KATSE RESERVOIR:		
Full Supply Level (FSL)	masl	2053
Storage at FSL	MCM	1950
Minimum Operating Level (MOL)	masl	1989
Storage at MOL	MCM	431.4
Active Storage Volume @ EL 2053.00	MCM	1518.6
Initial Storage	% of ASV	60
Inflow Sequences	MCM	1930 – 1995
Mean Annual Inflow	MCM/a	554.8
Instream Flow Requirement (Treaty)	m ³ s ⁻¹	0.50
Adopted Outlet Capacity for low flows (1.2 – 1.9)	m ³ s ⁻¹	1.55
Adopted Outlet Capacity for Floods (100 – 260)	m ³ s ⁻¹	180
MOHALE RESERVOIR:		
Full Supply Level (FSL)	masl	2075
Storage at FSL	MCM	946.93
Minimum Operating Level (MOL)	masl	2005
Storage at MOL	MCM	89.81
Active Storage Volume @ EL 2075.00	MCM	857.12
Initial Storage	% of ASV	60
Inflow Sequences	MCM	1930 – 1995
Mean Annual Inflow	MCM/a	308.8
Instream Flow Requirement (Treaty)	m ³ s ⁻¹	0.30
Adopted Outlet Capacity for low flows (2.5 – 4.25)	m ³ s ⁻¹	3.4
Adopted Outlet Capacity for Floods	m ³ s ⁻¹	57
MASHAI RESERVOIR:		
Full Supply Level (FSL)	masl	1887
Storage at FSL	MCM	3438.4
Minimum Operating Level (MOL)	masl	1835
Storage at MOL	MCM	1005
Active Storage Volume @ EL 1887.00	MCM	2433.4
Initial Storage	% of ASV	60
Inflow Sequences	MCM	1930 – 1995
Incremental Mean Annual Inflow	MCM/a	819.3
Instream Flow Requirement (Treaty)	m ³ s ⁻¹	1.5
Pumping Capacity from Mashai to Katse (30 – 50)	m ³ s ⁻¹	50
MATSOKU DIVERSION:		
Full Supply Level (FSL)	Masl	2088.5
Ratio of downstream versus natural annual inflows	%	36%
Instream Flow Requirement (Treaty)	m ³ s ⁻¹	0.05
MOHALE TUNNEL:		
Length	Km	32
Diameter	M	4
Flow Diversion computed based on storage levels at Katse and Mohale Dams.		

SECTION 5. MINIMUM DEGRADATION SCENARIO

5.1 HYDROLOGY

The Minimum Degradation IFRs were designed to minimise future degradation of the downstream rivers or, for the river reach immediately downstream of the existing Katse Dam, to indicate what minimum degradation could have been like. They represent the hypothetical "best case" situation with dams in place as it was assumed that the IFRs were not limited by dam design or yield commitment. For IFR Site 2 - downstream of Katse Dam - this scenario used the pre-Katse hydrological data.

For all parts of the affected rivers, the modified flow regimes encompassed two kinds of reduction - in the *range* of low flows and in the *number* of floods. For instance, in the wet season, the range of low flows at IFR Site 1 was reduced from 0.02-6.75 m³ s⁻¹ to 0.02-6.00 m³ s⁻¹, and at IFR Site 6 from 1.69-434.00 m³ s⁻¹ to 1.69-224.00 m³ s⁻¹. Similarly the dry season low flow ranges at IFR Site 1 were reduced from 0.00-4.03 m³ s⁻¹ to 0.00-4.00 m³ s⁻¹, and at IFR Site 6 from 0.90-120.00 m³ s⁻¹ to 0.90-70.00 m³ s⁻¹. Thus, it was indicated that proportionally more low flow could be lost from the downstream sites than from the upstream sites without serious impacts to river ecosystems.

With respect to floods, the main losses allowed were a reduction in the number of the smallest (Class 1) within-year floods and, at some sites, the largest (Class 4) within-year floods, since these were deemed to have very similar functioning to the Class 2 and 3 floods, respectively. Thus, the number of Class 1 floods at IFR Site 3 was reduced from seven to five per annum, and at IFR Site 5 from four to two per annum. The number of Class 4 within-year floods was reduced from two to one per annum at IFR Site 1, but no reduction of the natural flood situation was imposed at IFR Site 4. The remaining within-year floods at each site were distributed proportionally according to their natural occurrence. The 1:5 year flood was omitted for all sites on the assumption that the other major floods (1:2, 1:10, 1:20 year) would maintain most of the same flood functioning.

For each site, the volumes encompassed in the new flow regime were estimated and compared to the present Mean Annual Runoff (MAR). In total, the modified flow regimes comprised 55-67% of the present-day MAR (Table 5.1). Summary values in Table 5.1 are provided for comparison purposes only. If actually applied, the releases from the dams would have to be based on the capping levels for low flows and the flood volumes provided in the detailed biophysical scenario report (No. 648-F-04).

5.2 BIOPHYSICAL CONSEQUENCES

The reduced flow regimes were expected to result in subtle shifts in river condition. A negligible (0-10%) or low (10-20%) increase in the proportion of mud in the rivers, and in its deposition at river margins and in backwaters, was predicted. A concomitant increase in the growth of slippery biofilms on underwater surfaces was also expected. These changes were anticipated to be most obvious (20-40%) in the reaches downstream of Katse

(IFR Reach 2) and Mashai (IFR Reach 4) dams. The lower Senqu River (IFR Reach 6) and lower Senqunyane River (IFR Reach 8) would be least affected (0-5% change).

At the same levels of change, there would be a decrease in the movement of sand, gravel, cobbles and boulders along the rivers. Over short periods more sand might accumulate in flow-sensitive cobble riffles and in pools and thereby reduce their depths but, providing catchment erosion does not increase, larger floods would periodically reverse this trend. Geomorphological impact would be at most a slight reduction of inundation of wider, macro-channel elements (bars, benches and mini-floodplains) that would reduce the exchange of sand, nutrient-rich fine sediments and organic matter between rivers and banks.

Table 5.1 Hydrological summary of the IFRs for the Minimum Degradation Scenario. Shaded sites represent reaches immediately downstream of Phase 1 and 2 dams. MCM a⁻¹ = millions of cubic meters of water per annum.

IFR Site	Historical MAR	Minimum Degradation Scenario	
	MCM a ⁻¹	MCM a ⁻¹	As % of MAR
1	87	51	59%
2	554	366	66%
3	774	436	56%
4	1572	866	55%
5	1924	1194	62%
6	3330	2171	65%
7	355	231	65%
8	592	397	67%

Water quality changes were difficult to predict without details of the chemical and physical characteristics of the outflows, but in general it was considered that there would be mild increases in dissolved nutrients and suspended solids in the river water. Thus, in quiet waters where the suspended solids could settle out, an increase in the occurrence of algae was expected, and in faster-flowing areas, the water was expected to be slightly more turbid than under present-day conditions.

The channel and inundation changes described above would affect the riparian vegetation, whilst both these and the water quality changes would impact the aquatic plants and animals. There would be a negligible to low decrease in the abundance of annual plants, shrubs and trees growing at all levels up the banks. The most important social use of these is for medicines, while other uses listed are firewood, traditional attire, handicrafts, food, building construction, grazing, ropes, yokes, bank stabilisation, fodder and grazing. Their loss may be partly countered by a very mild increase in grasses and sedges in the same areas, and of large water plants (macrophytes) in the river itself. These kinds of shifts in plant communities, including the proliferation of algae, would be most obvious closest to the dams, diminishing downstream, with a change in abundance of only 0-5% predicted for IFR Reaches 5 (Whitehills) and 8 (lower Senqunyane). IFR Reach 6 (Seaka Bridge) differs from this trend, with a higher (10-20%) shift from shrubs and trees to sedge and grasses, which is mainly a reflection of the different shape of the river channel in this reach.

The changes in river-bed substrata, temperature and water quality would encourage a mild shift in aquatic invertebrate communities from fast-water to slow-water species. Conditions would be slightly more conducive for aquatic worms, the intermediate snail hosts of liver fluke parasites in domestic livestock, and the blackfly pest that targets poultry.

The major impact on fish would be confined to the Matsoku River, where the simple presence of the weir would disrupt movement of fish along the channel and might affect spawning and migration cues. It is predicted that there would be a moderate (11-50%) decrease in abundance of the Maloti Minnow and a severe (40-80%) decrease in trout numbers. The remaining fish species do not occur in the Matsoku River upstream of the waterfall but, in the rest of the river system, are predicted to show a negligible decrease (large mouth and small mouth yellowfish, rock catfish) or increase (Orange River mudfish) in abundance.

Amphibians (e.g., *Rana vertebralis*), used for bait by local fishermen, would show a negligible decline in numbers in all the mountain reaches, particularly near to the dams. They do not occur in the lower reaches. Other amphibians (e.g., *Xenopus laevis*), also used as bait, would increase slightly in abundance.

Most water-dependent birds and terrestrial mammals living in the riparian zones would be relatively unaffected by these subtle changes in the flow. The darter, which forages for fish in deep pool, is expected to be most affected. This bird, which is not used by people along the rivers, is predicted to decline in numbers by up to 25%.

In summary, most measurable changes under this flow regime were expected to be mild (Table 5.2). Information for Site 3 is provided, but this site would be inundated if Mashai were built. The major noticeable impact would be due to the Matsoku Weir, which from its presence, would disrupt life-cycle and migration requirements for the Maloti Minnow and trout. The unmeasurable changes need to be heeded, however, for they are poorly understood. There would be a loss of resilience in the system such that future disturbances would be less easily absorbed. As well as the general decline described above, the whole system would become a little less stable, with the condition (health) of the rivers declining a little, more often and more quickly than at present.

The level of impact of this scenario can be very broadly summarised as follows (Figures 5.1 and 5.2):

- IFR Site 1: Low/moderate (denoted moderate because of the effect on the Maloti Minnow);
- IFR Site 2: Inundated;
- IFR Site 3: Inundated;
- IFR Site 4: Low;
- IFR Site 5: Low;
- IFR Site 6: Negligible;
- IFR Site 7: Low;
- IFR Site 8: Negligible.

Table 5.2 Component specific summary for each IFR Site for the Minimum Degradation Scenario with Phase 1 and 2 dams in place. Severity ratings were coded as follows: blue – negligible; green – low; yellow – moderate; purple – severe; red – critically severe.

Subcomponent	IFR Site 1	IFR Site 2	IFR Site 3	IFR Site 4	IFR Site 5	IFR Site 6	IFR Site 7	IFR Site 8
Geomorphology	L	M	N	M	L	N	L	N
Water quality	L	L	L	L	L	N	L	N
Vegetation	L	M	L	L	L	L	N	N
Macroinvertebrates	L	L	L	L	L	L	L	L
Fish	M	N	N	N	N	N	N	N
Amphibia	N	N	N	N	N	N	N	N
Mammals and Birds	N	N	N	N	N	N	N	N

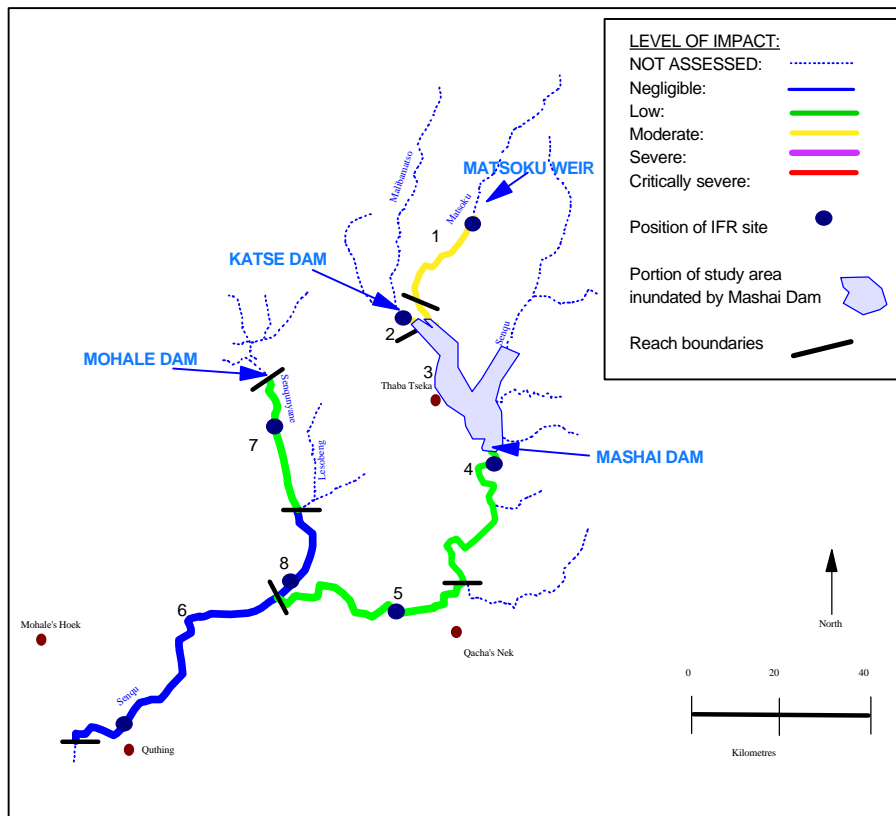


Figure 5.1 Broad summary of the likely severity of the biophysical impacts downstream of the LHWP Phase 1 and 2 dams (i.e., with Mashai Dam in place) under the Minimum Degradation Scenario.

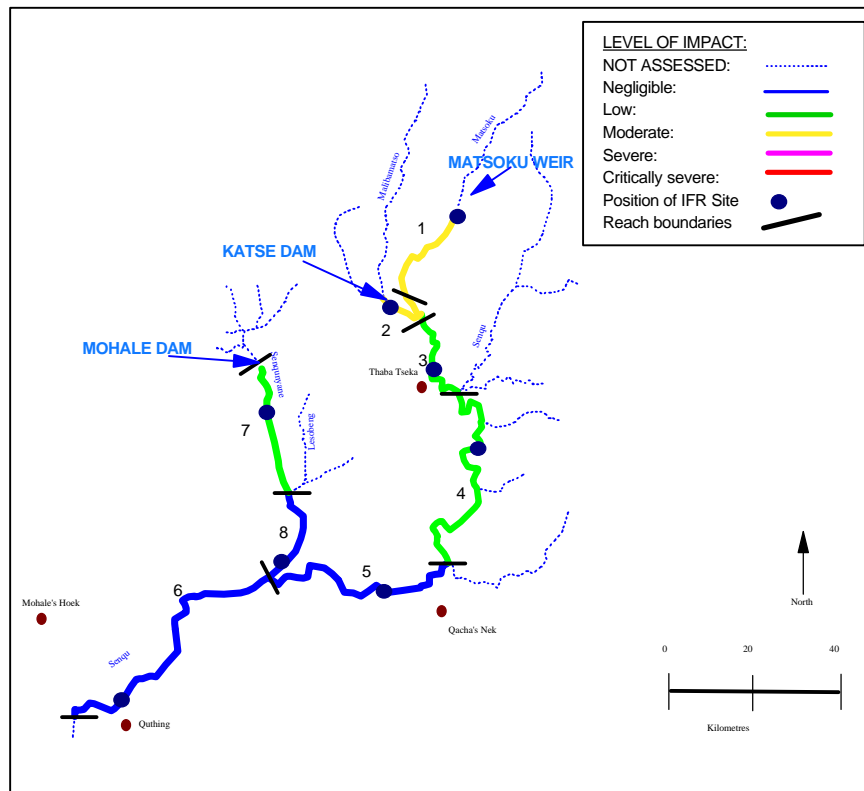


Figure 5.2 Broad summary of the likely severity of the biophysical impacts downstream of the LHWP Phase 1 dams (i.e., without Mashai Dam) under the Minimum Degradation Scenario.

5.3 SOCIAL IMPACTS

A relatively small change of river condition (i.e., minimal degradation) was not expected to affect use of the rivers by the PAR and, in general, the predicted social impacts were less severe than the corresponding biophysical changes. The Minimum Degradation Scenario was expected to have a slight (low) impact on the abundance of, and hence on the level of use of, wild vegetables, herbs, some shrubs and trees, and fish.

No significant health impacts were predicted. However, the general baseline health condition of the people in the corridor communities was already poor. While the rivers did not constitute a serious health risk, levels of stomach parasites capable of causing diarrhoea were recorded at IFR Sites 1, 2, 6 and 7 (*Giardia*), and at IFR Sites 2 and 3 (*E. coli*).

5.4 ECONOMIC IMPACTS

Since no significant human or domestic livestock health impacts were expected, no mitigation costs would be required in this scenario. Resource losses and associated compensation costs were computed for the slight reductions in riverine resources (Table 5.3). Most losses would be due to the blockage of fish by the Matsoku Weir, with relatively little loss due to flow reductions in other river reaches.

Table 5.3 Annual social losses and costs associated with the Minimum Degradation Scenario.

Cost Type	Component	Monetary Value
Resource losses* ¹		
	Fish* ²	683,127
	Forage	33,797
	Medicinal plants	37,126
	Wild vegetables	324,875
	Trees & shrubs	2,325,412
Sub-Total		3,404,337
Mitigation Costs* ³		
	Public health	0
	Animal health	0
Sub-Total		0
Total		3,404,337
* ¹ Based on local trade values		
* ² Total loss assumed for Reach 1 (Matsoku), proportional losses for other reaches		
* ³ Costs of avoiding health impacts		

5.5 WATER YIELD

The system yield (using an annual reliability of 98%) associated with the Minimum Degradation Scenario is indicated in Table 5.4.

Table 5.4 Estimated system yields (m³ s⁻¹) for the Minimum Degradation Scenario.

Phase 1	Phase 2
18.3	38.0

SECTION 6. TREATY SCENARIO

6.1 HYDROLOGY

The Treaty Scenario described the flow regimes in the study rivers with stipulated Treaty releases from Katse and Mohale Dams and, since they are currently not specifically indicated, assumed Treaty releases from Mashai and Matsoku. These releases were modelled as passing through the river systems and the resulting flows at each IFR site analysed using the DRIFT method. The flows used were:

- constant flows of 0.5 and 0.3 m³s⁻¹ for Katse and Mohale Dams respectively,
- a constant release of 0.05 m³s⁻¹ through Matsoku Weir,
- a constant release of 1.5 m³s⁻¹ from Mashai Dam (equivalent to the value used in the feasibility study and in the re-optimisation studies).

Of the four scenarios, this one assigned the least amount of water to the rivers. Flows were 4-5% of the present-day MAR at the IFR sites downstream of Katse Dam and Matsoku Weir and 8-13 % at IFR sites downstream of Mashai and Mohale Dams (Table 6.1). This proportion increased with distance from the dams as inflows from the tributaries augmented the flows in the rivers. At Paray, the percentage of MAR under Treaty conditions was 12%, and was higher in the Senqu and Senqunyane Rivers upstream of their confluence (25-27%), with the highest proportion for the Seaka Bridge site (43%).

Low flows and within-year floods were severely affected. For instance, downstream of Katse Dam, at IFR Site 2, the range of wet-season low flows was reduced from 0.02-6.75 m³s⁻¹ to 0.02-0.20 m³s⁻¹. Most within-year floods were removed. Those remaining were mostly of the smallest magnitude (Class 1) and were generated in the catchments well downstream of the dams. Of the larger floods, only the 1:20 year flood was retained. At IFR Site 1, on the Matsoku River, the floods were not as severely affected, since it was anticipated that the 1:2 year and larger floods would pass over the weir.

6.2 BIOPHYSICAL CONSEQUENCES

The impacts of the Treaty flow regimes on the rivers were the most severe of any of the scenarios and manifested as strongly deteriorating physical and chemical conditions. Almost all aspects of geomorphology and water quality were predicted to show severe and/or critically severe changes at seven of the eight IFR sites. Because of incremental inflow from the surrounding catchments, the lower Senqu (Reach 6) and lower Senqunyane (Reach 8) rivers were expected to be the least affected.

Immediately downstream of the dams critically severe changes were predicted in most physical and chemical aspects. Drastic reductions in pool numbers, depths and sizes, were anticipated, with pools disappearing almost completely in the higher reaches. The transport of sand, and shifting, scouring and sorting of larger bed elements was expected to virtually cease, except during very rare large floods. The anticipated consequences of this were that riverbeds would increasingly silt up, with all but the few remaining areas with slightly faster flow gradually

acquiring a relatively featureless, muddy bottom. Riffles would be largely or completely lost in many reaches, and deep, soft deposits of mud would line river margins and fill backwaters. There would be little of the habitat diversity and clean, scoured rock surfaces necessary for a diverse, healthy aquatic community. Conditions would improve somewhat after rare, large floods, but increasingly larger floods would be necessary to reverse the deterioration as these changes became entrenched, and the biota would show increasingly weak recovery after such floods due to failing numbers.

Table 6.1 Hydrological summary of the IFR for the Treaty Scenario. Shaded sites represent reaches immediately downstream of Phase 1 and 2 dams. For IFR Sites 4, 5 and 6 the IFR volumes with (Ph2) and without Mashai Dam (Ph 1) in place are provided. MCM a⁻¹ = millions of cubic meters of water per annum.

IFR Site	Historical MAR MCM a ⁻¹	Treaty Scenario	
		MCM a ⁻¹	As % of MAR
1	87	4	5%
2	554	22	4%
3	774	95	12%
4(Ph1)	1572	781	50%
4(Ph2)		130	8%
5(Ph1)	1924	880	46%
5(Ph2)		486	25%
6(Ph1)	3330	1964	59%
6(Ph2)		1439	43%
7	355	48	13%
8	592	158	27%

The reductions in low flows were expected to lead to widespread distribution of dense algal growths, particularly in Reaches 1, 2 and 4. There would also be a reduction in the temperature buffering capacity of the rivers with daily ranges of water temperatures increasing, as the small volumes of cold water released from the dams warmed up during the day but less so at night. This effect could be mitigated in the Senqu by mixing releases from different levels in Mohale Dam wall, to match as closely as possible the temperature of the water flowing into the top end of the reservoir.

Except for Reaches 6 and 8, wetbank vegetation was expected to show moderate (20-40%) to severe (40-80%) changes and the drybank vegetation severe to critically-severe changes, with an increased potential for encroachment of exotic, woody vegetation (such as *Acacia dealbata*).

Predicted shifts in invertebrate abundance were largely in the moderate (20-40%) to severe (40-80%) categories. There were as many increases in abundance predicted as decreases, and the overall abundance of organisms would theoretically remain the same. However, many replacement species would live in muddy deposits rather than on rocks and would be less accessible as food than those that were lost, therefore there would be a substantial decline in animal food available for fish and birds.

Predicted shifts in the community composition of the aquatic invertebrates were indicative of strongly deteriorating river health. Conditions of slower flows and higher nutrient and algal levels, suited for colonisation of disease-vector snails (carrying liver fluke), would be enhanced, particularly in Reach 1 where temperatures would be less seriously affected than downstream of the larger dams. The blackfly, *Simulium damnosum*, which attacks man, cattle and poultry, would increase in abundance downstream of Mohale Dam, and *Simulium nigrifarse*, which is a bloodsucker preying on poultry, was expected to increase, particularly in the Paray area and downstream of Mohale Dam.

The native and exotic fishes of the system were expected to be critically affected. The loss of fast-water, clean river substrata, migratory and spawning cues, food organisms, and deep pools in which to avoid predation and freezing winter temperatures would reduce abundance to the point of local extinctions. The Maloti Minnow and trout would disappear from the Matsoku downstream of the weir. Additionally, trout, large-mouth and small-mouth yellowfish and rock catfish would become extremely rare or absent from Reaches 2, 3 and 4. Where relevant in terms of their present distributions, they would also be moderately to severely reduced in numbers in Reaches 5, 6, 7 and 8. Orange River mudfish were expected to show a concomitant increase in abundance, particularly in Reaches 2 and 4 (40-100% or more), and negligible to moderate increase in the remaining reaches where they occurred.

Moderate to severe decreases in the abundance of the *Rana* group of amphibians were also predicted for Reaches 1 to 5 and 7. Conversely, the *Xenopus laevis* group was expected to increase in abundance. Although more species would decline than increase in numbers, it was not clear if overall numbers would change to the point that availability of bait would be affected.

A widespread loss of water-dependent bird life along the rivers was anticipated, largely due to the loss of fish, especially in Reaches 1 to 4. African black duck, giant kingfisher and hammerkop, all used for meat or medicine, were expected to show moderate to severe declines in abundance, as were darters, black-headed herons, three-banded plovers and white-breasted cormorants, which had no social significance. Conversely, increases in some small mammals, viz. multimammate mouse, red musk shrew and striped mouse, sometimes possibly to plague proportions, were predicted.

In summary, the loss of resistance and resilience within the system was expected to be clearly apparent (Table 6.2) and the loss of river resources to riparian people, and deterioration in the general health of the river, substantial. The capacity to dilute and transport all pollutants, including faecal contaminants, was also expected to decline. The potential negative consequences of drinking river water would thus increase sharply. The potential for future development of the catchment areas or the remaining water and other resources in the rivers would be compromised, as additional disturbance of the rivers or catchments were expected to result in further declines in river condition.

Table 6.2 Component specific summary for each IFR Site for the Treaty Scenario with Phase 1 and 2 dams in place. Severity ratings were coded as follows: blue – negligible; green – low; yellow – moderate; purple – severe; red – critically severe.

Subcomponent	IFR Site 1	IFR Site 2	IFR Site 3	IFR Site 4	IFR Site 5	IFR Site 6	IFR Site 7	IFR Site 8
Geomorphology	CS	CS	S	CS	S	S	S	M
Water quality	CS	CS	S	CS	S	M	CS	L
Vegetation	S	S	S	S	S	M	S	M
Macroinvertebrates	CS	CS	CS	CS	M	L	S	L
Fish	CS	CS	CS	CS	S	S	CS	M
Amphibia	S	S	M	S	M	L	S	L
Mammals and Birds	S	S	S	S	M	M	L	L

The level of impact of the Treaty Scenario can be broadly summarised as follows (Figure 6.1):

- IFR Site 1: Critically-severe;
- IFR Site 2: Inundated;
- IFR Site 3: Inundated;
- IFR Site 4: Critically-severe;
- IFR Site 5: Severe;
- IFR Site 6: Moderate;
- IFR Site 7: Severe;
- IFR Site 8: Moderate.

Indications of the expected extent of downstream recovery without Mashai Dam are provided in Figure 6.2.

6.3 SOCIAL IMPACTS

The predicted loss of wild vegetables, herbs and fish reported under the biophysical consequences, would result in a considerable reduction in the consumption of these items. Similarly there would be fewer vegetables and fish to sell. The most important conclusion from previous nutritional studies of the Katse and Mohale catchment communities was that LHWP rural populations are extremely vulnerable from a nutritional point of view. Because communities are so poor, their staple diets consist mainly of carbohydrate type foods (maize and sorghum). Protein in the form of meat and dairy products is not frequently consumed. Fish is thus an important source of protein for those communities that have active fishermen. Similarly, the nutrients provided by riparian vegetables are important.

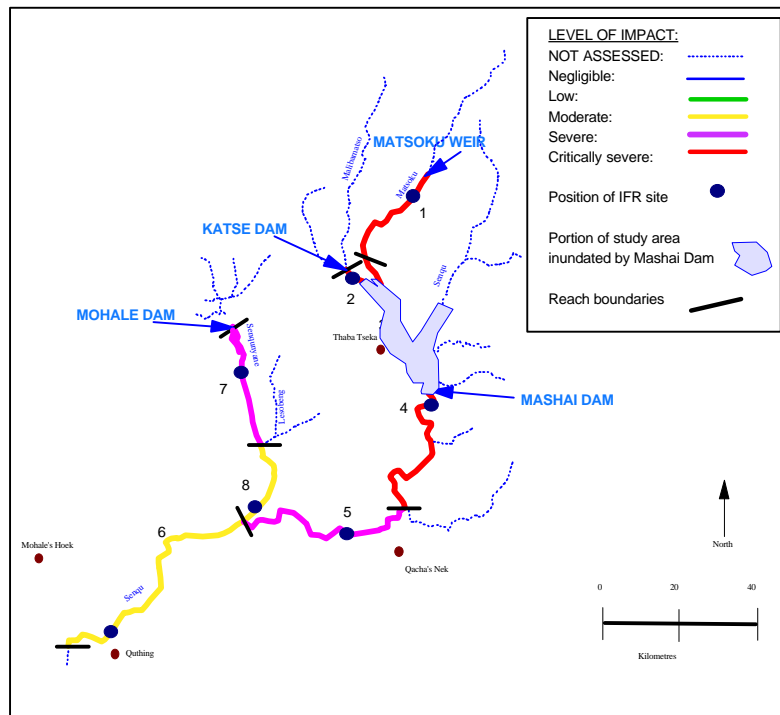


Figure 6.1 Broad summary of the likely severity of the biophysical impacts downstream of the LHWP Phase 1 and 2 dams (i.e., with Mashai Dam in place) under the Treaty Scenario.

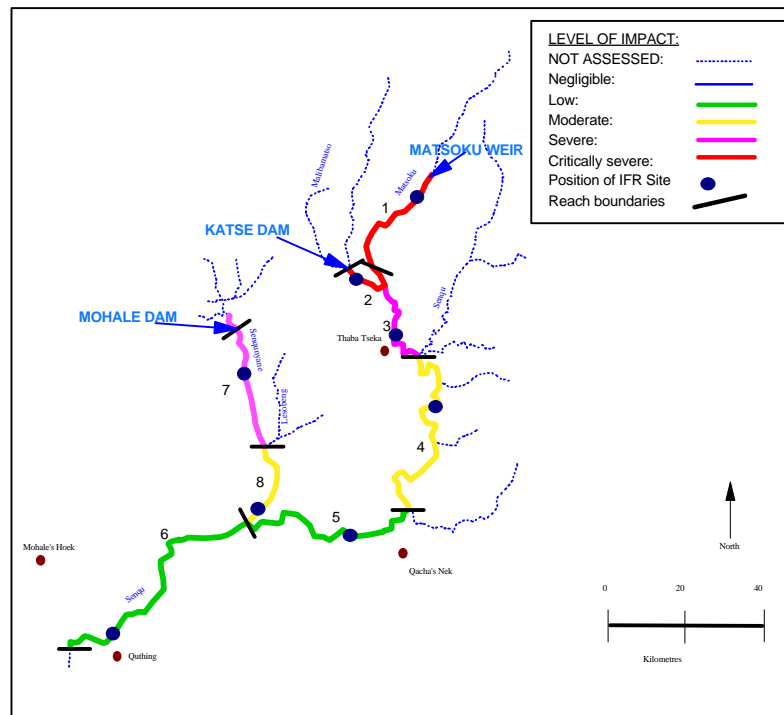


Figure 6.2 Broad summary of the likely severity of the biophysical impacts downstream of the LHWP Phase 1 dams (i.e., without Mashai Dam in place) under the Treaty Scenario.

In the reaches immediately downstream of the dams, reductions in the abundance of vegetables, herbs and fish were expected to exceed 50%. This could have one of two possible repercussions.

- Use of the particular resource might cease because of low availability. Studies focusing on 'perceptions of loss' along the highly affected Malibamats'o River downstream of Katse Dam suggest that the concept of "*it's not worth going there any more*" is fairly dominant among affected communities. This means that if the availability of a resource is reduced by a large amount, it becomes essentially valueless since communities think in cost-benefit terms due to, amongst other factors, the long and strenuous hike down to the river to gather the resource in question.
- The decline of resources, if not mitigated or compensated for, could lead to over-utilisation and ultimately to collapse of the remaining resources.

The added health impacts associated with the Treaty Scenario could be extremely serious. Critically severe impacts were expected for diarrhoeal disease and nutrition. The risk of *Schistosomiasis* becoming established in the reaches immediately downstream of the dams could increase although the actual establishment of the host snails in the rivers has a low probability. The incidence of skin and eye diseases for those reaches was expected to be severe. Minimal impact was expected for malaria and anthrax. Examples of the sorts of problems that would likely be experienced were already available from IFR Reach 2, immediately downstream of Katse Dam. Villagers in this reach reported that the impacts in terms of public health downstream of Katse Dam were severe. Many villagers reported the water was too contaminated to use safely as drinking water and they complained about skin rashes after they crossed, or swam in, the river. The poor water quality was said to be caused by the growth of algae (*bolele*) due to reduced flow and the incidence of small black insects (*thalaboliba*, *maphele*, *mankulunyane*) occurring in the water.

While only a slight increase in the incidence of livestock diseases and/or injuries was anticipated under the Treaty Scenario, the nuisance value of pests such as *Simulium nigrifarse*, a pest of poultry, was expected to increase noticeably.

6.4 ECONOMIC IMPACTS

The annual resource losses for the predicted reduction in riverine resources and the costs of mitigation of health-related impacts are shown in Table 6.3. The values given here assume Mashai is in place. The reflected losses of riverine resources exclude the complete loss of resources associated with submerged reaches of the river, i.e., IFR Reaches 2 and 3. In computation of loss of resources, these two reaches should be treated as impoundments.

Table 6.3 Annual social losses and costs associated with the Treaty Scenario.

Cost Type	Component	Monetary Value	
		With Mashai Dam (Phase 2)	Without Mashai Dam
Resource losses* ¹			
	Fish* ²	5,935,936	5,680,190
	Forage	346,288	362,240
	Medicinal plants	163,067	181,931
	Wild vegetables	1,470,636	1,446,827
	Trees & shrubs	8,862,849	8,425,451
	Sub-Totals	16,778,777	16,096,640
Mitigation Costs* ³			
	Public health	713,042	741,703
	Animal health	325,549	325,549
	Sub-Totals	1,038,590	1,067,252
	Totals	17,817,367	17,163,891
* ¹ Based on local trade values			
* ² Total loss of resource use assumed for Reach 1 (Matsoku), proportional losses for other reaches			
* ³ Costs of avoiding health impacts			

6.5 WATER YIELD

The system yield (using an annual reliability of 98%) associated with the Treaty Scenario is shown in Table 6.4 for Phase 1 and 2 of the LHWP.

Table 6.4 Estimated system yields ($\text{m}^3 \text{s}^{-1}$) for the Treaty Scenario.

Phase 1	Phase 2
27.3	50.8

SECTION 7. DESIGN LIMITATION SCENARIO

7.1 HYDROLOGY

This scenario describes the consequences of imposing design-limited releases from the Phase 1 and 2 dams on the downstream river reaches.

The effects of the physical dimensions of the LHWP structures (Annex E) and a commitment to delivery of a moderate yield were translated into hydrological parameters in two ways:

- average annual releases from the dams were limited to between 30% and 40% MAR as measured at the dam sites;
- instantaneous flow limitations were imposed by features of those structures already constructed (Katse Dam) or being constructed (Matsoku Weir, Mohale Dam); outflows from Matsoku were geared for the best seasonal distribution of low-flow releases, together with short-duration flushes, and it was assumed possible to release any proportion of the inflow from the weir if the outlet tunnel gates from Matsoku to Katse were kept closed; no limitations were imposed on the release structures of Mashai Dam which is yet to be finally designed.

It was further assumed that:

- floods of 10 and 20 years return period would spill over all dams, except Katse, where only to the flood of 20 years return period would spill;
- floods of 2 to 5 years return period would not be released from the dams.

The hydrological computations applied to the Design Limitation Scenario were as follows:

- the flow regimes at the IFR sites immediately downstream of the dams and weir (IFR Sites 1, 2, 4 and 7) were determined first according to the limitations described above;
- thereafter, the flow regimes at IFR sites further downstream were estimated using the continuity of flow approach and historical data.

Within the limits set by the criteria, high and low flows could be combined in many ways to create modified flow regimes for the rivers. In an iterative process, combinations of high and low flows that were deemed to be least-damaging to the rivers were selected. In general, the Design-Limitation flow regimes were derived by reducing those described for the Minimum Degradation Scenario in two ways.

- The range of low flows was reduced to a level between the Minimum Degradation and Treaty Scenarios. For instance, the present-day range of wet-season low flows at IFR Site 1 was $0.02\text{-}6.75\text{ m}^3\text{ s}^{-1}$. The top of the range was reduced to $6.00\text{ m}^3\text{ s}^{-1}$ in the Minimum Degradation Scenario, and to $3.00\text{ m}^3\text{ s}^{-1}$ in this scenario. Similarly the present-day, dry-season range of low flows was set at $0.00\text{-}4.03\text{ m}^3\text{ s}^{-1}$. The top of the range was reduced through $4.00\text{ m}^3\text{ s}^{-1}$ to $1.00\text{ m}^3\text{ s}^{-1}$ in this scenario.

- The number of floods of all four classes of within-year floods were reduced, most to the level of only one or no occurrence per annum. The 1:2 and 1:5 year floods were eradicated, but the 1:10 and 1:20 year floods remained.

In total, these modified flow regimes comprised 33-53% of the present-day MAR (Table 7.1). The lowest percentages (33-35%) were immediately downstream of the three major dams, and the values increased down the rivers to the highest percentage (53%) at Site 6. Details of the calculations are given in the Hydrology Report (No. 648-F-13). The actual releases from the dams, should this scenario be adapted, would have to be based on the capping levels for low flows and the flood volumes provided in the detailed scenario report (No. 648-F-06).

Table 7.1 Hydrological summary of the IFRs for the Design Limitation Scenario. Shaded sites represent reaches immediately downstream of Phase 1 and 2 dams. For IFR Sites 4, 5 and 6 the IFR volumes with (Ph2) and without Mashai Dam (Ph 1) in place are provided. MCM a⁻¹ = millions of cubic meters of water per annum.

IFR Site	Historical MAR	Design Limitation Scenario	
	MCM a ⁻¹	MCM a ⁻¹	As % of MAR
1	87	35	40%
2	554	184	33%
3	774	315	41%
4(Ph1)	1572	832	53%
4(Ph2)		542	34%
5(Ph1)	1924	1010	52%
5(Ph2)		829	43%
6(Ph1)	3330	1965	59%
6(Ph2)		1781	53%
7	355	126	35%
8	592	254	43%

7.2 BIOPHYSICAL CONSEQUENCES

Degradation of the rivers from their present condition would be noticeably greater than for the Minimum Degradation Scenario but less than for the Treaty Scenario. Severe (40-80%) to critically severe (80 to >100%) changes were expected to be confined to the channel or riverbed. The predicted biological responses to physical change were generally more muted, with those most directly linked to the physical changes showing the greatest response. Substrata were expected to be less well sorted, so that physical heterogeneity of the riverbed would be reduced. Thus, the diversity of physical habitats would be gradually lost, and many plant and animal species that depend on well-sorted, scoured substrata were expected to decline or disappear from the system.

Physical changes were anticipated to be most apparent in the reach downstream of Katse Dam, followed by the reach at Paray and those downstream of Matsoku Weir and Mohale Dam. Loss of mobilisation of nutrients and

fine sediments was expected to lead to substantial build-ups of mud in the rivers, sedimentation of clean cobble areas, loss of both numbers and depths of pools and a decline in water quality. Thus, in pools, the loss of water depth would be exacerbated by them being turbid and nutrient-rich more often than at present, with an increased likelihood of algal blooms, particularly in the reaches downstream of the dams, where there could be critically severe (80 to >100%) increases in algal occurrences.

Different vegetal species in the wetbank zone, nearest to the open water, would reflect negligible, low or moderate (0-40%) increases or decreases in abundance at all sites, but changes in the outer drybank zone would be more extreme.

Impacts on the instream fauna would be most severe for fish. The Maloti Minnow and rainbow trout are predicted to drastically decline in abundance and possibly to disappear from the Matsoku reach downstream of the weir. All other native fish species, except the Orange River mudfish, would also show a severe (40-80%) loss of numbers downstream of Katse and Mohale Dams, with a less drastic reduction elsewhere in the system. The Orange River mudfish would exhibit a negligible to low (1-20%) increase in numbers.

Most shifts in invertebrate abundance would be negligible to moderate (0-40%), but there would be more extreme changes (up to 75%) in the abundance of blackflies. Among those, the most probable change of greatest social significance is a predicted 40-60% increase in numbers of *Simulium nigritarse* downstream of Mohale Dam.

Amongst terrestrial wild animal species associated with the rivers, there would be a negligible to low loss of abundance, and possibly an eventual loss of diversity of frog species, particularly at Reaches 2, 3, 4 and 7. Most water-dependent birds would suffer no or only negligibly low loss of abundance, while more serious, moderate losses are predicted for darters, three-banded plovers, giant kingfishers and white-breasted cormorants. Thirteen of these bird species are used for meat or medicine. An occasional moderate increase of terrestrial pests such as the multimammate mouse (Reaches 1-5,7) or the red musk shrew (Reach 6), and an accompanying moderate loss of white-tailed mice are expected.

In summary, the predicted biological responses were modest compared to the predicted physical and chemical changes (Table 7.2). However, although change would be less severe than for the Treaty Scenario, the ability of the rivers to resist change (i.e., their *resistance*) or to "bounce back" after disturbance (i.e., their *resilience*) would have been greatly reduced. The ability to recover from such downward swings into poor condition would be jeopardised by any further decline in catchment condition or increase in catchment development. Thus this scenario illustrates the limiting effect on future development of such a reduced flow regime. If development were not limited, the condition of the rivers would rapidly decline beyond that described here, because they would already be stressed, with a substantially reduced capacity for absorbing more disturbance.

Table 7.2 Component specific summary for each IFR Site for the Design Limitation Scenario with Phase 1 and 2 dams in place. Severity ratings were coded as follows: blue – negligible; green – low; yellow – moderate; purple – severe; red – critically severe.

Subcomponent	IFR Site 1	IFR Site 2	IFR Site 3	IFR Site 4	IFR Site 5	IFR Site 6	IFR Site 7	IFR Site 8
Geomorphology	S	S	S	M	M	M	S	M
Water quality	M	M	M	L	L	L	M	N
Vegetation	M	M	M	M	L	L	M	L
Macroinvertebrates	M	S	M	M	M	L	S	L
Fish	S	S	N	M	M	M	S	
Amphibia	L	M	M	M	N	N	M	N
Mammals and Birds	L	L	L	L	L	N	L	N

The level of impact of this scenario can be very broadly summarised as follows (Figure 7.1):

- IFR Site 1: Severe (denoted severe because of the impact on the Maloti Minnow);
- IFR Site 2: Inundated;
- IFR Site 3: Inundated;
- IFR Site 4: Moderate;
- IFR Site 5: Low to moderate (denoted as low);
- IFR Site 6: Low;
- IFR Site 7: Severe;
- IFR Site 8: Low.

An indication of the expected extent of downstream recovery without Mashai Dam is provided in Figure 7.2.

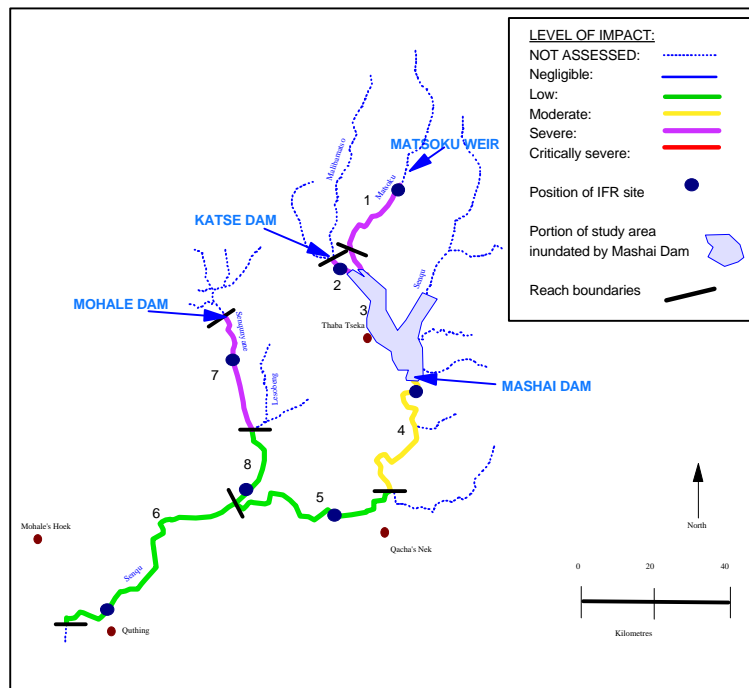


Figure 7.1 Broad summary of the likely severity of the biophysical impacts downstream of the LHWP Phase 1 and 2 dams (i.e., with Mashai Dam in place) under the Design Limitation Scenario.

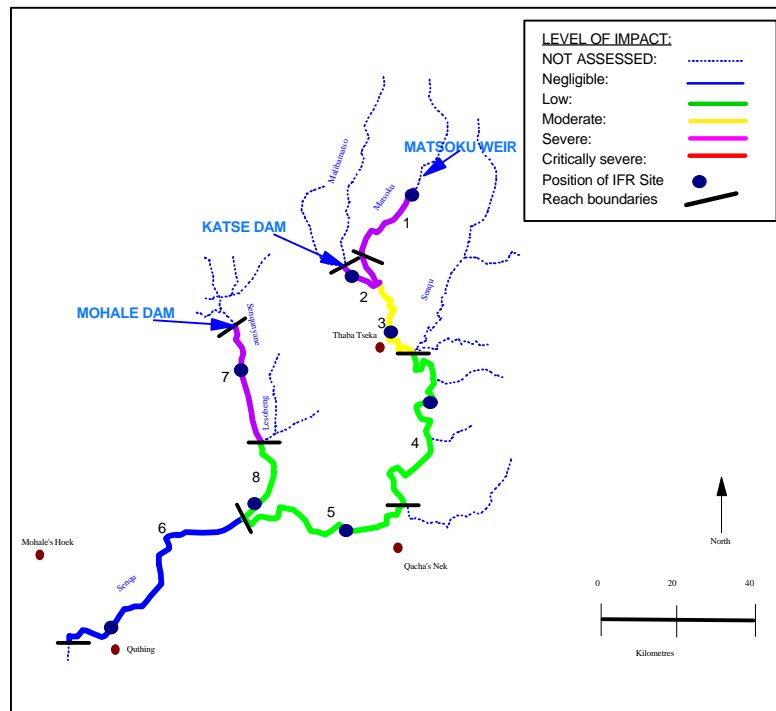


Figure 7.2 Broad summary of the likely severity of the biophysical impacts downstream of the LHWP Phase 1 dams (i.e., without Mashai Dam in place) under the Design Limitation Scenario.

7.3 SOCIAL IMPACTS

The social impacts associated with the Design Limitation Scenario can be summarised as moderate. In simple terms this means that although there would be a reduction in the river resources used by the PAR, this reduction would tend to be less than 50% for most of the resources used. The notable exceptions to this are fish, which are expected to decline dramatically in the reaches immediately downstream of the dams. There are, however, concerns that, if the resources that are lost are not compensated for, then the potential for extensive over-utilisation of the remaining resources would be great, thus leading to their eventual decrease below harvestable levels.

For public health, moderate impacts are expected for diarrhoeal disease and nutrition, although these could be severe immediately downstream of the dams. It is likely that the rivers would not present any more of a health risk than they do at present for much of the time, but there would be occasions when they represent a serious health risk. It is difficult to predict the frequency of these occasions, other than to say that they would be more often than at present, but probably less often than under the Treaty Scenario. An example could be in summer when temperatures were high, runoff from rainfall was also high (faeces are washed off the surrounding areas into rivers during times of rain) but the flow in the rivers was considerably lower than natural, and thus the dilution would be lower. Such water would have a higher than present level of faecal contaminants and parasites such as *Giardia*, with a concomitant increased health risk for those drinking or bathing in the water. Minimal impact is expected for *Schistosomiasis*, malaria and anthrax.

As with the Treaty Scenario, a slight increase in the incidence of livestock diseases and/or injuries and in the nuisance value of pests such as *Simulium nigritarse*, a pest of poultry, are anticipated under the Design Limitation Scenario.

7.4 ECONOMIC IMPACTS

The annual resource losses for the predicted reduction in riverine resources and the costs of mitigation of health-related impacts are shown in Table 7.3.

7.5 WATER YIELD

The system yield (using an annual reliability of 98%) associated with the Design Limitation Scenario is shown in Table 7.4 for Phase 1 and 2 of the LHWP. The losses excludes complete loss of resources at Reaches 2 and 3 submerged by Mashai reservoir.

Table 7.3 Annual social losses and costs associated with the Design Limitation Scenario.

Cost Type	Component	Monetary Value
Resource losses* ¹		
	Fish* ²	2,629,158
	Forage	69,717
	Medicinal plants	143,289
	Wild vegetables	1,074,038
	Trees & shrubs	5,367,955
	Sub-Total	9,284,156
Mitigation Costs* ³		
	Public health	499,480
	Animal health	165,609
	Sub-Total	665,089
	Total	9,949,245
* ¹ Based on local trade values		
* ² Total loss assumed for Reach 1 (Matsoku), proportional losses for other reaches		
* ³ Costs of avoiding health impacts		

Table 7.4 Estimated system yields (m³ s⁻¹) for the Design Limitation Scenario.

Phase 1	Phase 2
22.8	43.6

SECTION 8. FOURTH SCENARIO

8.1 HYDROLOGY

The Fourth Scenario was designed at the request of the LHDA as a fourth point, located between the Design Limitation and Treaty Scenarios. The volume of water allocated for river maintenance was between those allocated in these other two scenarios, with approximately 10-18% of the MAR at the major dam sites allocated as dam releases. The percentage of MAR passing through sites further downstream increased, due to incremental catchment contributions. This concept is implied wherever the term "10-18% of MAR" is used. The 10-18% rule did not apply to IFR Site 1 as it is expected that there would be substantial spills from the weir. At IFR Site 1, the percentage MAR used for the Fourth Scenario was 36% based on the present design of Matsoku Diversion.

Within the above MAR limits, many different combinations of high and low flows could be set. Combinations were chosen that would provide a river condition that was approximately midway between those conditions described for the Design Limitation and Treaty Scenarios. The same hydrological procedures applied for the Design Limitation Scenario were applied for the Fourth Scenario.

The resulting flow regimes, compared to the Treaty Scenario, increased the range of wet-season low flows at all sites, whilst maintaining them lower than for the Design Limitation Scenario. The range of dry-season low flows was also higher than for the Treaty Scenario for most sites. The numbers of within-year floods of all classes were in most cases intermediate between the two other scenarios, although for a few sites the level of reduction of low flows left some "spare" water that could be added as extra small floods. This helped reduce some of the potential geomorphological degradation described in the Design Limitation Scenario, with the result that in these respects the Fourth Scenario did not necessarily sit intermediate between the other two.

In total, flow regimes comprised 18-49% of the present-day MAR (Table 8.1). The percentages downstream of the three major dams were 18-22%. At reaches further downstream (Reaches 3, 5 and 8) the values increased to 29-37% of MAR.

Approximately 36% of the MAR passed through and over Matsoku Weir, and the highest value was at Seaka Bridge (Reach 6) with 49% of its present MAR. The summary values provided in Table 8.1 are for comparison purposes only. The actual releases from the dams would have to be based on the capping levels for low flows and the flood volumes provided in the detailed scenario report (No. 648-F-07).

8.2 BIOPHYSICAL CONSEQUENCES

The consequences for the rivers are described in Report No. 648-F-07, and represent a range of subtle shifts in river condition from those described for the Design Limitation and Treaty Scenarios. The predicted condition of

the rivers was an improvement on that linked to the Treaty Scenario, but not to the point that it equalled that linked to the Design Limitation Scenario (Table 8.2).

Table 8.1 Hydrological summary of the IFRs for the Fourth Scenario. Shaded sites represent reaches immediately downstream of Phase 1 and 2 dams. For IFR Sites 4, 5 and 6 the IFR volumes with (Ph2) and without Mashai Dam (Ph 1) in place are provided. MCM a⁻¹ = millions of cubic meters of water per annum.

IFR Site	Historical MAR	Fourth Scenario	
	MCM/a	MCM/a	As % of MAR
1	87	31	36%
2	554	97	18%
3	774	226	29%
4(Ph1)	1572	703	45%
4(Ph2)		288	18%
5(Ph1)	1924	1010	52%
5(Ph2)		720	37%
6(Ph1)	3330	1964	59%
6(Ph2)		1620	49%
7	355	77	22%
8	592	195	33%

Table 8.2 Component specific summary for each IFR Site for the Fourth Scenario with Phase 1 and 2 dams in place. Severity ratings were coded as follows: blue – negligible; green – low; yellow – moderate; purple – severe; red – critically severe.

Subcomponent	IFR Site 1	IFR Site 2	IFR Site 3	IFR Site 4	IFR Site 5	IFR Site 6	IFR Site 7	IFR Site 8
Geomorphology	S	S	S	S	M	M	S	M
Water quality	S	S	M	S	M	L	S	N
Vegetation	M	S	M	S	S	M	S	M
Macroinvertebrates	M	S	M	M	M	L	S	L
Fish	CS	CS	S	CS	M	M	S	M
Amphibia	L	N	M	M	N	N	M	N
Mammals and Birds	L	L	L	L	L	N	L	N

The level of impact of this scenario can be very broadly summarised as follows (Figure 8.1):

- IFR Site 1: Severe;
- IFR Site 2: Inundated;
- IFR Site 3: Inundated;
- IFR Site 4: Severe;
- IFR Site 5: Moderate;
- IFR Site 6: Low;
- IFR Site 7: Severe;
- IFR Site 8: Low.

An indication of the expected extent of downstream recovery without Mashai Dam is provided in Figure 8.2.

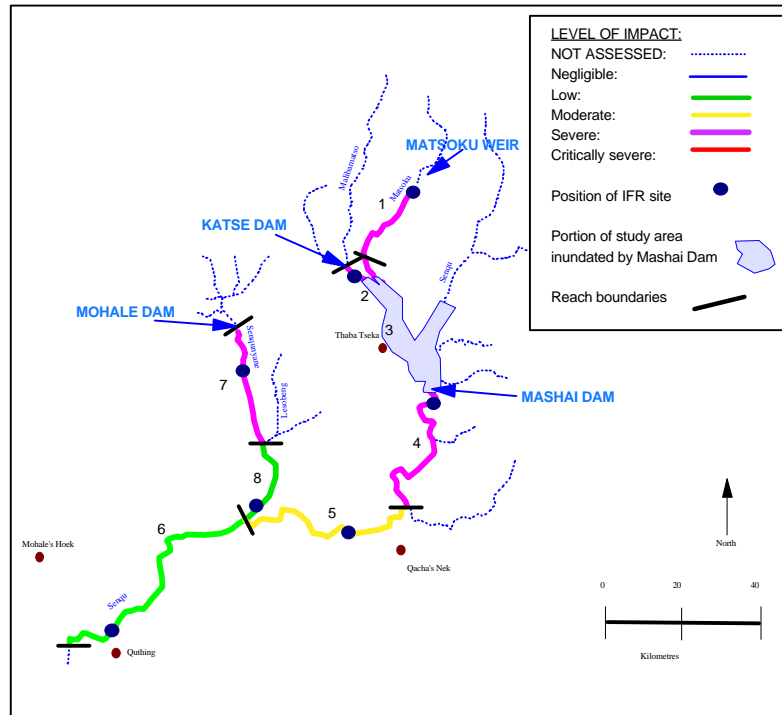


Figure 8.1 Broad summary of the likely severity of the biophysical impacts downstream of the LHWP Phase 1 and 2 dams (i.e., with Mashai Dam in place) under the Fourth Scenario.

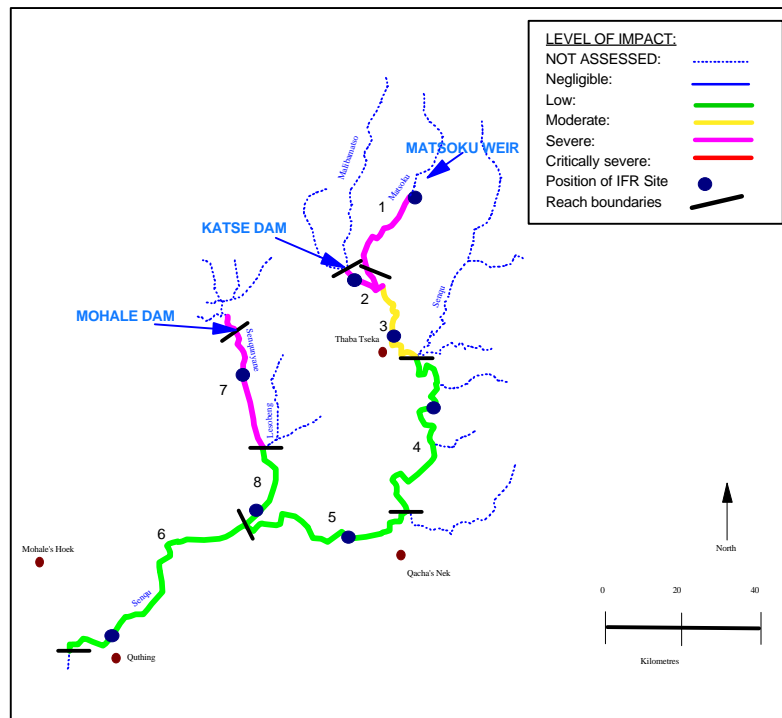


Figure 8.2 Broad summary of the likely severity of the biophysical impacts downstream of the LHWP Phase 1 (i.e., without Mashai Dam in place) under the Fourth Scenario.

8.3 SOCIAL IMPACTS

As with the biophysical consequences, the impacts on cultural and subsistence use of river resources and those on public health were less severe than those linked to the Treaty Scenario, but not to the point that they equalled those linked to the Design Limitation Scenario. The exception was animal health, where the impacts linked to the Fourth Scenario were expected to be very similar to those linked to the Design Limitation Scenario.

8.4 ECONOMIC IMPACTS

The annual resource losses for the predicted reduction in riverine resources and the costs of mitigation of health-related impacts are shown in Table 8.3.

8.5 WATER YIELD

The system yield (using an annual reliability of 98%) associated with the Design Limitation Scenario is shown in Table 8.4 for Phase 1 and 2 of the LHWP. The losses exclude complete loss of resources at Reaches 2 and 3 submerged by Mashai Reservoir.

Table 8.3 Annual social losses and costs associated with the Fourth Scenario.

Cost Type	Component	Monetary Value	
		With Mashai Dam (Phase 2)	Without Mashai Dam (Phase 1)
Resource losses* ¹			
	Fish* ²	4,668,903	3,160,728
	Forage	75,512	88,652
	Medicinal plants	146,510	174,476
	Wild vegetables	1,113,444	1,213,963
	Trees & shrubs	7,228,445	7,005,651
	Sub-Totals	13,232,824	11,643,259
Mitigation Costs* ³			
	Public health	685,003	713,664
	Animal health	177,312	177,312
	Sub-Totals	862,315	890,976
	Totals	14,095,139	12,534,446
* ¹ Based on local trade values			
* ² Total loss of resource use assumed for Reach 1 (Matsoku), proportional losses for other reaches			
* ³ Costs of avoiding health impacts			

Table 8.4 Estimated system yields (m³ s⁻¹) for the Fourth Scenario.

Phase 1	Phase 2
25.2	47.8

SECTION 9. WATER DEMAND AND SUPPLY

The details of this component of the study are presented in the Water Demand and Supply Report No. 648-F-11.

9.1 INTRODUCTION

9.1.1 Objective of the Water Demand and Supply Study

The objective of this study was to assess the water needs of communities downstream of LHWP dams, and the extent of their dependence on the study rivers, in order to ascertain the volume of water that should be released from the dams to meet these needs. It was agreed with the LHDA that the volume of water required to meet the needs of the communities would be in addition to the volume of water required to meet the needs of the downstream aquatic environment (i.e., IFR releases).

9.1.2 Methods Used

Most of the data required were available from previous water-resource studies in Lesotho (see Report No. 648-F-11), or were collected as part of other components of this study (e.g., Sociological Report No. 648-F-08). Estimates of water demand integrated population growth, changing needs and habits related to water consumption, and dependency of rural people and their domestic animals on the study rivers. Predictions were made of overall domestic demand at the present time and in the future. System losses in the water-conveyance system were based on recommendations of GoL water supply studies.

9.2 WATER DEMAND AND SUPPLY

The total water demand for the study area, i.e., without taking cognisance of where the water was obtained from, is provided in Table 9.1.

The outcome of the assessment of dependence on the study rivers was as follows.

- On average, 80 percent of the households within the 5 km river corridor on either side of the river obtained their domestic water from taps or springs.
- Two percent of the households used the study rivers as their main source of water all year round.
- Five percent of households used the river as a main water-supply source during the dry season.
- Eleven percent of households used the river as a main water-supply source during periods of drought.
- Thirty-two percent of livestock were watered at the study rivers in the dry season.
- Sixty-two percent of livestock were watered at the study rivers during periods of drought.

Table 9.1 Estimated total water demand in the study area in 1999 and projected to 2020.

Reach	Representative Site	Total Water Demand ($\text{m}^3 \text{s}^{-1}$)					
		1999			2020		
		Household	Livestock	Total	Household	Livestock	Total
1	Matsoku at Seshote	0.003	0.004	0.007	0.004	0.006	0.010
2	Malibamats'o at Katse	0.001	0.001	0.002	0.002	0.002	0.003
3	Malibamats'o at Paray	0.006	0.004	0.010	0.008	0.006	0.014
4	Senqu at Sehonghong	0.011	0.009	0.019	0.015	0.012	0.026
5	Senqu at Whitehills	0.011	0.007	0.019	0.015	0.010	0.025
6	Senqu at Seaka Bridge	0.024	0.021	0.045	0.033	0.028	0.061
7	Senqunyane at U/S Marakabei	0.004	0.007	0.011	0.006	0.009	0.015
8	Senqunyane at Nkaus	0.001	0.001	0.003	0.002	0.002	0.004
Totals		0.063	0.054	0.117	0.085	0.073	0.159

From these facts the following conclusions have been drawn.

- Only a fraction of the total water demand summarised in Table 9.1 was obtained from the study rivers;
- There was a clear seasonal pattern to the use of the study rivers for domestic water, with greatest reliance being during periods of drought, presumably because other water sources had then dried up. Because of this, it was recommended that the water demands during drought be used to assess the water needs of communities downstream of LHWP dams.

The water demands on the study rivers in average, dry and drought periods were provided for present day (1999) and in 20 years time (2020) (Table 9.2).

Table 9.2 Total water demand from the study rivers per IFR reach during average, dry and drought periods.

IFR Reach No	Average Period $\text{m}^3 \text{s}^{-1}$		Dry Period $\text{m}^3 \text{s}^{-1}$		Drought Period $\text{m}^3 \text{s}^{-1}$	
	1999	2020	1999	2020	1999	2020
1	0.003	0.004	0.003	0.004	0.004	0.005
2	0.000	0.000	0.000	0.000	0.001	0.001
3	0.002	0.003	0.002	0.003	0.002	0.003
4	0.004	0.005	0.004	0.005	0.006	0.008
5	0.002	0.002	0.002	0.002	0.005	0.006
6	0.004	0.006	0.007	0.010	0.019	0.019
7	0.003	0.004	0.003	0.004	0.005	0.006
8	0.000	0.000	0.000	0.000	0.001	0.001
Totals	0.019	0.025	0.022	0.030	0.043	0.049

IFR Reach 1 was the only reach with a significant water demand during the dry and drought period relative to the flow in the river. It was recommended that provisions should be made for extra releases at this site. The water

demands at the remaining IFR reaches were low and probably did not warrant releases from LHWP dams specifically to meet them.

There was a potential for irrigation in the lowland areas, specifically in IFR Reach 6. The estimated volume of water required to meet the demand of the irrigation potential in the entire Senqu and Senqunyane catchments was $0.36 \text{ m}^3 \text{ s}^{-1}$ (given in Report No. 648-F-11).

SECTION 10. DISCUSSION OF SCENARIOS

10.1 PURPOSE OF SECTION

This section summarises the main findings of the IFR study and relates them to the design and possible operation of the LHWP Phase 1 and the eventual design of Phase 2. This section and the succeeding one are framed so as to provide a bridge between the scientifically-designed and executed IFR study and the needs of decision-makers who will determine the ways and means of operating and further designing the LHWP. The design of the IFR study with its detailed biophysical and socio-economic comparison of scenarios which range from minimal environmental degradation, on one hand, to near-maximum diversion of system flows on the other, provides a comparative basis for drawing important conclusions on river ecosystem resilience and sustainability. The substantial biophysical and socio-economic database provided by the study furthermore provides a quantitative basis for comparative conclusions and for future refinement of IFR determinations.

10.2 ISSUES RELEVANT TO THE TIMING OF THE IFR ASSESSMENT

Under more ideal conditions the IFR study would have preceded major design and operating decisions for the LHWP. This was not the case, and the IFR study was commissioned well after the construction of Phase 1A and during the course of final design and initial construction of Phase 1B. A number of significant changes have occurred between the mid 1980s, when Phase 1 of the LHWP was studied and designed and the LHWP Treaty was formulated and signed, and 1997 when the IFR study was initiated.

- Phase 1 was designed and Phase 1A constructed on the assumption that downstream impacts resulting from diversion of more than 95% of the MAR would be limited to the proximal reaches of the Malibamats'o and Senqunyane rivers immediately downstream of the LHWP structures and above the confluences of the next major tributaries (Khohlontso and Semenanyane for the Malibamats'o, Lesobeng for the Senqunyane). This has been shown by the IFR study not to be the case, and significant hydrological, biophysical and socio-economic changes will be measurable all the way to the Lesotho border.
- The assumption seems to have been made in the initial stages of the LHWP that local people made very little use of riverine and riparian resources downstream of the LHWP structures. No studies or assessments of these were conducted. This lack of use has been shown not to be the case, and the IFR field studies have documented an extensive and sometimes complex relationship between local people and river-related resources such as riparian trees, shrubs and herbaceous species. Utilisation of the fish resource by local people has to date been largely ignored, whereas the IFR study has documented extensive fish harvesting and local trade in the downstream river reaches.
- The existing LHWP compensation programme has to date addressed the impacts only in the areas upstream of the LHWP structures. The IFR study has documented extensive existing and potential future economic impacts downstream of the structures.

10.3 BIOPHYSICAL IMPACTS

Table 10.1 summaries the predicted biophysical consequences of various levels of flow regulation for each of the study reaches. Reaches are separated into two classes - proximal (immediately downstream) to the LHWP structure and distant.

Table 10.1 Reach-specific summary of the combined biophysical consequences for each scenario with Phase 1 and 2 dams in place, viz. Katse, Mohale and Mashai Dams, and Matsoku Weir. In very general terms the level of impacts are coded as follows: Blue – negligible; Green – Low; Yellow – moderate; Purple – severe; Red – critically severe.

Reach		Minimum Degradation	Design Limitation	Fourth	Treaty
1	Proximal to dam or weir	M	S	S	CS
2		M	S	S	CS
7		L	S	S	S
4		L	M	S	CS
3	Distant from dam or weir	L	M	M	S
5		N	L	M	S
6		N	L	L	M
8		N	L	L	M

The Minimum Degradation Scenario serves as a baseline comparison. Removal of 30-40% of the MAR in the form of large inter-year as well as a significant proportion of small intra-year floods and reduction of dry season baseflows by a small proportion would lead to only slight or negligible biophysical changes in most downstream reaches. Moderate biophysical changes would likely be measured in the reaches downstream of Katse Dam and Matsoku Weir; these would largely be comprised of geomorphological changes and impacts to local fish populations caused by the structures themselves.

At the other end of the spectrum, critically severe biophysical changes are expected, and are being observed in the case of Katse Dam, in the reaches downstream of the structures where $\geq 95\%$ of the MAR has been diverted. The intermediate Design Limitation and Fourth Scenarios are intermediate in terms of their MAR requirements and their predicted biophysical changes. An important observation is that the most severe changes would be expected in the proximal river reaches, with considerably lower impacts in the more distant reaches. A comparison of the levels of severity of biophysical impact at each IFR site and the percentage of MAR hypothesised for each site (Figure 10.1) confirms the general positive correlation between the two variables. For the same proportion of MAR, proximal reaches show a more severe change than do distant reaches. There is also a wide range of variation in the biophysical responses. For example, a reduction of MAR of 40% at one site could lead to a predicted biophysical impact categorised as "low" while at another site the response might be

much more severe e.g., "severe". This suggests a highly specific biophysical response at the various sites to the flow regime imposed reflecting the characteristics of the channel and biota in that reach. It also indicates that attempts to adjust a flow regime to achieve a particular response, e.g., to minimise biophysical impacts, would require a reach specific assessment. A general rule of thumb applied to entire river systems might well lead to erroneous results.

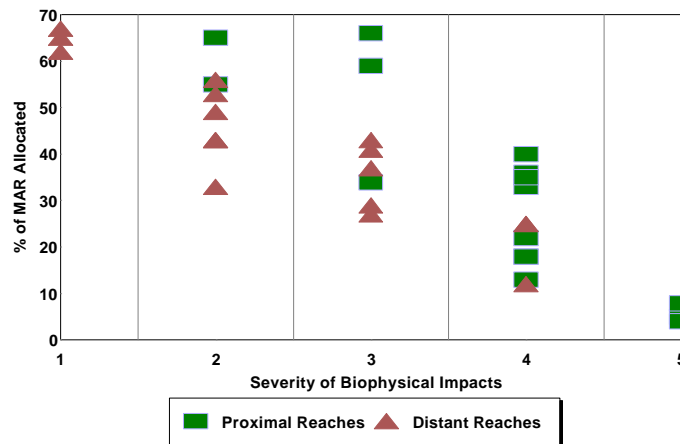


Figure 10.1 Comparison of % MAR diverted in various reaches with the severity of biophysical changes in those reaches.

10.4 SOCIAL IMPACTS

Table 10.2 summarises the severity of social impacts (in the absence of any specific mitigation and compensation programmes) predicted for the various river reaches. These are correlated with the biophysical impacts but display a different pattern of distribution, perhaps influenced by the distribution of communities in relation to the various reaches and the local geomorphology, which influences the distribution and abundance of important resources such as fish, trees and herbs, and the extent to which communities gather and utilise these resources. The Treaty Scenario leads to critically severe social impacts through resource depletion in the reaches immediately downstream of Katse and Mashai Dams and downstream of the Matsoku Weir. The table demonstrates that there are few differences in the severity of downstream social impacts in reaches located some distance from the controlling structures between any of the scenarios with significant water diversions. This factor is discussed further in Section 11.

10.5 PUBLIC HEALTH IMPACTS

Table 10.3 summarises the predicted public health impacts in the various river reaches. As noted in sections above, the downstream communities were already at some risk from water- and sanitation-related diseases before the development of the LHWP which will exacerbate the existing poor situation through reductions in river flows and periodic flushing.

Table 10.2 Reach-specific summary of the combined socio-economic consequences for each scenario with Phase 1 and 2 dams in place, viz. Katse, Mohale and Mashai Dams, and Matsoku Weir. In very general terms the level of impacts are coded as follows: Blue – negligible; Green – Low; Yellow – moderate; Purple – severe; Red – critically severe.

Reach		Minimum Degradation	Design Limitation	Fourth	Treaty
1	Proximal to dam or weir	L	M	M	CS
2		L	S	S	CS
7		L	M	M	CS
4		L	M	S	S
3	Distant from dam or weir	L	S	S	S
5		L	S	S	S
6		L	M	M	S
8		N	M	M	M

Table 10.3 Reach-specific summary of the public health consequences for each scenario with Phase 1 and 2 dams in place, viz. Katse, Mohale and Mashai Dams, and Matsoku Weir. In very general terms the level of impacts are coded as follows: Blue – negligible; Green – Low; Yellow – moderate; Purple – severe; Red – critically severe.

Reach		Minimum Degradation	Design Limitation	Fourth	Treaty
1	Proximal to dam or weir	M	M	M	S
2		M	M	S	S
7		M	M	S	S
4		M	M	M	S
3	Distant from dam or weir	M	M	S	S
5		M	M	M	S
6		M	M	M	M
8		M	M	M	M

10.6 ANIMAL HEALTH IMPACTS

Table 10.4 summarises the predicted animal health consequences of the various scenarios in the various river reaches. Effects on livestock are expected to be moderate at worst, even for the relatively severe Treaty Scenario, but would be reduced to much lower levels if higher river flows were permitted.

Table 10.4 Reach-specific summary of the animal health consequences for each scenario with Phase 1 and 2 dams in place, viz. Katse, Mohale and Mashai Dams, and Matsoku Weir. In very general terms the level of impacts are coded as follows: Blue – negligible; Green – Low; Yellow – moderate; Purple – severe; Red – critically severe.

Reach		Minimum Degradation	Design Limitation	Fourth	Treaty
1	Proximal to dam or weir	L	L	M	M
2		L	M	M	M
7		L	M	M	M
4		L	M	M	M
3	Distant from dam or weir	L	L	M	M
5		L	L	M	M
6		L	L	M	M
8		L	L	M	M

10.7 OTHER IMPACTS AND LOSSES

The IFR study did not exhaustively study or evaluate all possible consequences and effects of flow alteration in the rivers downstream of the LHWP structures. For reasons of time and cost constraints, emphasis was placed on the key biophysical factors and on socio-economic issues selected on the basis of experience in the upper catchments of the LHWP (reservoir areas) as being important in a community and project development context.

In addition to the economic value of their water, the rivers have many other, less tangible, attributes. A vitally important aspect not specifically addressed in this study was the intangible values associated with free-flowing rivers. Particularly in the African context, these are powerful and important forces. It is essential to incorporate consideration of them, and of the impacts of the full range of gains and losses in quality of life, into the decision on how to go forward with development of their water resources. The Senqu, Malibamats'o, Senqunyane, Matsoku and other rivers within the general zone of influence of the LHWP have great scientific value as representatives of African high-elevation headwaters with intrinsically valuable ecosystems, and are of cultural significance to the people who live close to them. In general, the less water diverted from such rivers, the closer to their natural potential they are likely to remain.

Linked to this is the tourism potential of the area, which was also not assessed in this study. Tourism is a development priority for Lesotho in general and the LHWP in particular. Some downstream river reaches, e.g., IFR Reaches 5 and 8, have scenic river values of very high potential for future tourism.

10.8 LOSSES AND COSTS IN RELATION TO DOWNSTREAM FLOW REGIMES

Examination of the amounts of resource losses estimated for the various scenarios as well as the estimated costs of avoiding or reducing human and animal health impacts (Figure 10.2) indicates a similar overall pattern to the tables presented above but shows up additional important relationships.

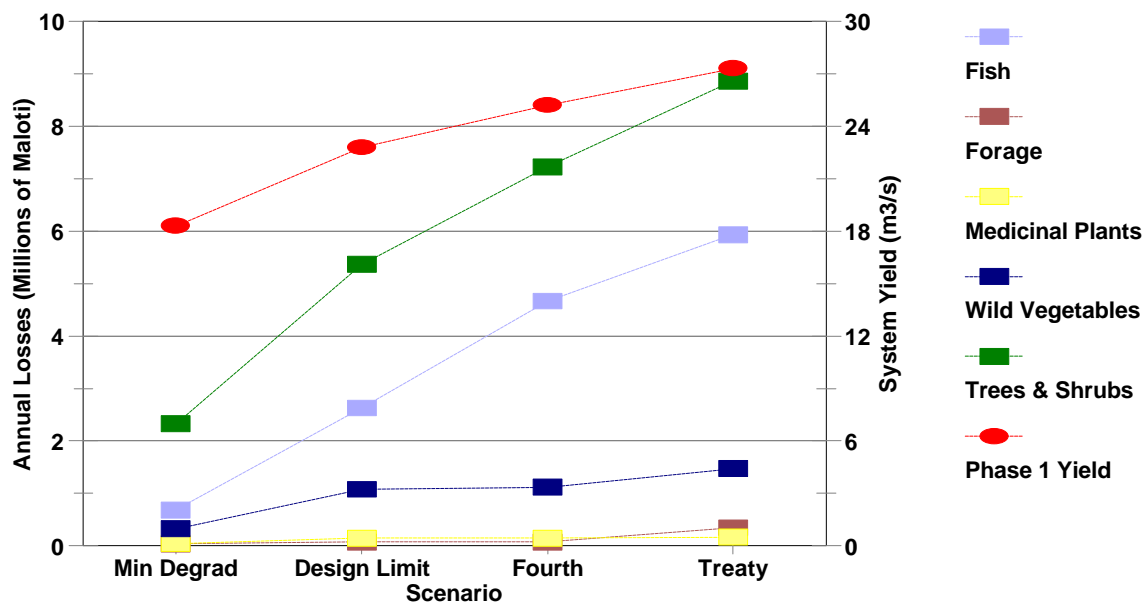


Figure 10.2. Estimated resource losses caused by the various LHWP scenarios compared to the predicted system yields for Phase 1 and Phase 2 in place.

- The relationship between extracted water yields from the system and the extent of resource losses is not linear over the ranges measured in the study. While the Treaty Scenario extracts 50 % more water from the system than does the Minimum Degradation one, the difference in resource losses is a much higher proportion (e.g., 8-fold higher for fish, approximately 4-fold higher for trees and shrubs, nearly 5-fold higher for total estimated losses and mitigation costs).
- Losses under the Treaty Scenario are also substantially higher than under a scenario in which relatively small additional downstream flows are allocated, e.g., overall estimated resource losses for the Treaty Scenario are 30% higher than under the Fourth Scenario, whereas the additional water yield is only ~6% more. The implication is that, in seeking to mitigate environmental impacts and reduce resource losses, the differences between the Treaty and Fourth Scenarios are likely to show up opportunities for achieving this without necessarily sacrificing large amounts of water yield.

- Costs of mitigation for public and animal health are relatively low in comparison to resource losses and the differences between scenarios not as marked. This stems from the nature of the mitigation, i.e., immunisation and sanitation measures are directed at communities and are not direct consequences of flow changes.

An examination of the distribution of resource losses (Table 10.5 for fish, Table 10.6 for vegetative resources) provides similar insights into the complexities of flow distribution and impacts. The allocation of more water consistently reduces the levels of resource loss in a fairly uniform way.

Table 10.5 Reach distribution of estimated annual fish resource losses (in millions of Maloti) for each scenario: blue < 1 million; green 1 - 2 million; yellow 2 - 3 million.

Reach		Minimum Degradation	Design Limitation	Fourth	Treaty
1	Proximal to dam or weir	0.1	0.1	0.1	0.1
2		0.0	0.1	0.1	0.1
7		0.1	0.4	0.4	0.4
4		0.2	0.5	2.3	2.5
3	Distant from dam or weir	0.0	0.1	0.3	0.5
5		0.1	0.5	0.6	0.9
6		0.2	1.0	1.7	1.8
8		0.0	0.0	0.0	0.0

Table 10.6 Reach distribution of estimated annual vegetation resource losses (in millions of Maloti) for each scenario: blue < 1 million; green 1 - 2 million; yellow 2 - 3 million; purple 3 - 4 million; red > 4 million.

Reach		Minimum Degradation	Design Limitation	Fourth	Treaty
1	Proximal to dam or weir	0.3	0.9	0.9	1.1
2		0.1	0.3	0.3	0.4
7		0.1	0.7	0.7	0.9
4		0.8	2.1	3.4	4.5
3	Distant from dam or weir	0.2	0.8	0.9	1.6
5		0.4	1.0	1.1	1.7
6		1.1	1.8	2.1	2.1
8		0.0	0.1	0.1	0.1

The following points are shown up by Tables 10.5 and 10.6:

- The bulk of the resource losses stems from those reaches with the highest PARs (Reaches 4,5 and 6).
- Although Reach 6 is distant from the LHWP structures, the economic impacts in this reach would be comparatively higher than in other reaches due to the higher PAR density and the correspondingly higher use of riverine resources.
- Fish resource losses would be significant in Reaches 4 and 6, both of which are accessible from existing roads, hence these reaches are good candidates for fisheries enhancement projects.
- Vegetation resources - medicinal plants, shrubs, trees and wild vegetables - would be heavily impacted in Reaches 4, 5 and 6, mainly as a consequence of the Mashai Dam. Social forestry programmes would be logical compensation measures in these areas.
- A comparison of the resource losses (quantified by the units used in the social surveys) estimated for the various scenarios along the entire length of the downstream reaches (Figure 10.3) indicates that proportional losses under the Treaty Scenario would be severe, with about 40% reduction in tree and wild vegetable harvests, 50% in shrubs & debris harvests, and nearly 70% reduction in fish harvests. These losses could be proportionally higher if the threshold effect described earlier becomes a reality. By comparison, losses under the Minimum Degradation Scenario would be an estimated 8-12% for each of the main resources harvested. Losses under the other scenarios would comprise from 25 to 50% of the estimated present harvests of fish, trees and wild vegetable materials.

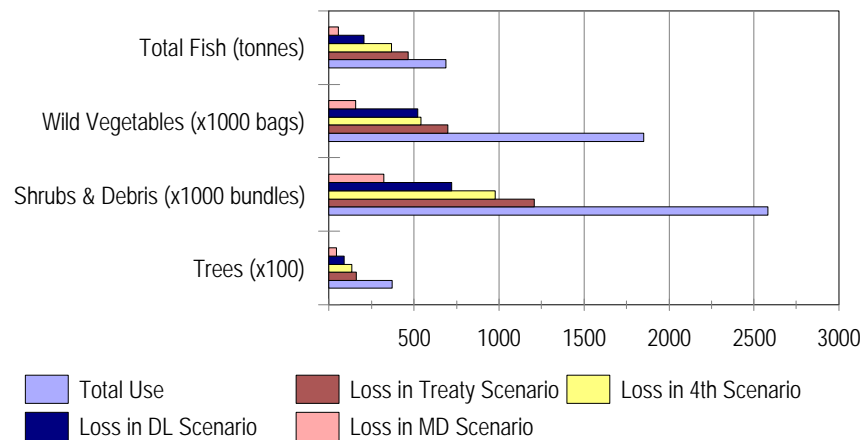


Figure 10.3. Comparison of resource losses due to the various LHWP scenarios.

SECTION 11. MITIGATION AND COMPENSATION

11.1 DEFINITIONS

The terms "*mitigation*" and "*compensation*" are used here in the conventional sense, mitigation meaning changes to project design, operations and/or project area management to reduce levels of impact and/or resource losses, while compensation refers to cash, goods or services offered to *replace* resources which are unavoidably lost or activities which are impeded as a result of project development and implementation. Both terms represent cost to the project but the proportions of each to total project cost and the ways in which the costs are calculated and apportioned may be quite different.

Both mitigation and compensation require some reference baseline condition for estimation. This is normally taken to be the defined pre-project situation, and this concept is inherent in the conditions of the Treaty (Section 1.2), which refers to existing standards of living of local communities and the existing quality of the environment. These standards and qualities, to the extent to which they can be adequately identified and measured, should logically become the objectives of mitigation and compensation programmes. The costs of implementing the mitigation measures, including any foregone benefits from the project, represent approximately the mitigation costs. It follows that an environmentally friendly project would have few if any mitigation costs, e.g., a water diversion scheme built to minimum degradation standards (Section 5).

The main form of mitigation for the downstream impacts of the LHWP is the release of water in amounts and at times which minimise the types of biophysical effects and social and economic consequences described in detail in this report and in the technical report series.

Two additional terms are used in the context of compensation. "*Compensation costs*" in the Economics Report (No. 648-F-22) is the shortfall in resource values caused by the project actions, i.e., the changes in downstream flow regime, which would have to be replaced to bring community welfare back to its supposed pre-project levels. It refers to the same amounts identified as "*resource losses*" used in this report. "*Compensation delivery costs*" is a term used below to indicate the extra costs that may be incurred to deliver the compensation to the communities in question. Whereas a particular community living near a particular reach may incur an estimated x Maloti loss in timber losses due to river flow reductions, it might cost a total of $x+y$ Maloti to deliver an equivalent amount of wood in compensation to that community, being the compensation delivery costs brought about by the setting up of a nursery, growing of seedlings, costs of transportation to the villages, and the costs of providing long-term extension services. Compensation delivery costs are frequently greater than zero in undeveloped rural situations where the resources impacted, e.g., fish, trees and plants, occur naturally and their production is provided as an unpaid service by the natural ecosystem.

Communities living within access of supply outlets might utilise alternatives or substitutes for resources impacted by the project, e.g., store-bought fish to replace wild caught fish no longer available, in which case the cost of the

substitute represents more accurately the value of the resource loss. However, the great majority of the people living downstream of the LHWP have no or, at best, difficult and tedious, access to alternative supply sources and the use of substitutes is not a practical consideration.

11.2 OPPORTUNITIES FOR MITIGATION

Mitigation of downstream impacts through adjustment of flow releases through the LHWP structures is inherent in the scenarios described above, e.g., the Minimum Degradation Scenario represents a very high level of mitigation (with a considerable cost in potentially divertable water) while the Treaty Scenario represents a very low level of mitigation with near-maximum diversion of the water resource. However, mitigation to meet required objectives can be fine-tuned and guided by information from the monitoring programme. The physical constraints on water releases created by the design of the various outlet facilities will affect the ways and timing of these releases. Annex E describes the LHWP outlet structures, and the salient features of the releases are as follows.

- Katse Dam can release between 1.2 and 1.9 m³ s⁻¹ through the mini-hydro bypass and between 150 and 400 m³ s⁻¹ through the low-level outlet, maximum discharges depending on reservoir volume. Floods overtopping the spillway are expected to occur very infrequently in the future and are treated as expected spills. The opportunities for mitigatory flow releases at Katse are thus very limited.
- Mohale Dam can release between 2.5 and 4.25 m³ s⁻¹ from its multiple-level offtakes and c. 45 m³ s⁻¹ through the low-level outlet (when the reservoir is at minimum operating level), discharges again depending on reservoir volume. Floods over the spillway are expected to be rare events. The increased flexibility allowed for by the Mohale outlets, probably means that there is a better opportunity for mitigating impacts in the Senqunyane River through planned flow releases.
- Matsoku Weir can discharge a maximum 0.65 m³ s⁻¹ through its weir outlet, while any flows exceeding 47 m³ s⁻¹ will pass through the scour gate to downstream, and flows exceeding 96 m³ s⁻¹ will overtop the spillway. Discharges through the scour gate and/or over the spillway are expected to occur in most years.

A significant problem in applying mitigation to the LHWP as it currently exists is that the entire scheme and its yields were designed on the basis of one set of engineering, economic and environmental assumptions (near-maximum diversion of water, maximisation of economic values of the yield, minimal concern for the downstream environment and communities) while the basis for application of an IFR is quite different (maximum concern for downstream environments and communities, optimisation of overall economic opportunities).

11.3 OPPORTUNITIES FOR COMPENSATION

Any compensation programmes aimed at the areas downstream of the LHWP structures would assumedly form part of the overall LHWP compensation programmes which are presently all concerned with items upstream of the LHWP structures and are embodied in the respective Phase 1A and 1B Environmental Action Plans. The current plans make no provision for downstream compensation, although they do address monitoring of downstream impacts on a long-term basis.

A key feature of the LHWP compensation programme as implemented upstream is that compensation-in-kind has dominated the transactions. Lost production from land has been replaced by maize and pulses delivered to communities, and livestock fodder has replaced foregone range forage. Social forestry programmes have

provided trees to replace lost timber resources. Where cash has been accepted by communities as a compensation measure, it has been directed to specific affected households. Virtually all lost community assets such as communal land resources have been replaced by other resources, not cash.

11.4 POTENTIAL MITIGATION AND COMPENSATION APPROACHES

The following is a brief review of potential mitigation and compensation approaches for downstream river reaches.

11.4.1 Fisheries

Cash compensation for lost fish harvests would not be workable in the case of downstream communities because of a lack of supply outlets for any fish or fish substitutes. The present fishery programme in Phase 1A is directed at the utilisation of the abundant fish populations in Katse reservoir, which are presently self-sustaining. The programme seeks to provide training to communities in fishing techniques and in methods of regulating harvests for long-term sustainability. Reservoir fish populations available for such harvesting are a natural product of reservoir formation and were not established specifically for utilisation purposes. The biological situation downstream is quite different - fish populations and associated harvests would be limited by stream flows and lack of available wetted habitats. Supplementation of fish populations for harvesting by local communities is theoretically possible through the establishment and operation of hatcheries and fish rearing facilities, but releasing fish into water-depleted rivers would be a largely pointless exercise. Fishery enhancement thus seems potentially more feasible in river reaches that are distant from the LHWP structures, that receive flows from tributaries not affected by flow regulation, and that have the advantage of accessibility from existing roads.

Local people utilise fish primarily as a food resource, and the aesthetics of fishing are secondary and likely a very minor concern. An alternative form of compensation would therefore be one that supplements the food quantity and quality available to downstream communities. This is dealt with further below.

11.4.2 Medicinal Plants

Estimated losses for the medicinal plant resources are comparatively low (about M165,000 annually for the Treaty Scenario) but overall biomass and cash values are not the only important parameters for medicinal plants - diversity and availability are also significant. Cash compensation is not a ready substitute for the lost resource because of this biological diversity, strong local beliefs in the efficacy of herbal medicines, and a lack of locally available substitutes.

In determining compensation approaches to medicinal plants, it is important to identify the main target of the compensation - the source or the users. Plants used for medical purposes are in great demand in the upstream areas and over-utilisation is regarded as a major threat to species survival. Compensation measures through the artificial propagation of selected species in the upstream catchment areas are intended to supply the market and relieve pressure on wild-grown plants. Such cultivation has yet to be proven to be effective and useful and, even if this is the case, production of the full range of medicinal plants used by local people will hardly ever be practically possible. In the downstream areas the long-term survival of medicinal plant species is not as great a

concern because of the linear nature of the area under impact and the availability of similar habitats along tributaries. The main objective downstream would be to compensate local users.

Replacement of herbal medicines by synthetics will unlikely ever be total, for even in urban centres such as Maseru medicinal plants are in demand. However, the experience of the public health compensation programme in Phase 1A indicates that local people will make use of modern clinical facilities if they are available. Hence, provision of adequate community public health would be partial compensation for lost medicinal plant resources.

11.4.3 Trees and Shrubs

The field studies undertaken suggested that annual tree harvests, mainly poplar and willow, within the study zones on either side of the rivers downstream of the LHWP structures amounted to about 37,000 trees. Flow regulation via the Treaty stipulations would reduce this number by approximately 40%. Releasing additional water, say 3.5 times more as in the Fourth Scenario, would make little difference because of the location of the trees on the upper benches of the river channel. It would require appreciably more water to be released to reduce these tree losses (e.g., the Design Limitation Scenario would reduce losses to 24% but necessitate a seven-fold increase in mean annual releases).

A community forestry programme has been in operation in the reservoir areas of Phase 1A for the past five years, set up and run by an international NGO. A 170,000 seedling capacity nursery near Ha Lejone provides mainly hardy conifers for outplanting in villages. Advisory and extension services are provided by NGO staff. Extension of the programme to areas downstream of the LHWP structures would be practical in terms of availability of expertise and local experience. Planting timber trees within actual village areas could not only potentially replace lost timber resources but would have the added advantages of providing easier access to the trees and the supplementary benefits of shade and windbreaks. Quite significant disadvantages would however be the extensive areas embraced by the downstream river reaches, the scattered nature of the villages and the lack of vehicle access to many parts.

Shrubs, tree branches, dead wood and other debris make up the bulk of the woody material harvested by local people along the downstream reaches, and could be as much as 15,000 - 20,000 tonnes annually, depending on how the field data are interpreted. This probably represents the bulk of the energy used by these communities for cooking. About half of this material would be lost to communities following flow reductions and, as in the case of timber, substantial increases in flows would be required to reduce the shortfall. This material would only partially be replaced by woodlot material from community forestry programmes. Adequate compensation of the energy value of gathered woody biomass would require much more ambitious tree plantings than currently applied in the reservoir areas or, alternately, might necessitate a technological leap to energy sources such as solar-powered cookers.

11.4.4 Wild Vegetables

Wild gathered roots, tubers, rhizomes, leaves, fruits and flowers are very important nutritional sources for rural people dependent on white maize and small quantities of other grains for their staple diet. The IFR field studies indicated a total harvest of something like 2000 tonnes of fresh biomass taken annually from the riparian zones.

Under the Treaty Scenario this would be reduced by approximately 40%, with the value of the resource loss estimated at about M1.4 million annually. The release of small amounts of additional water would not overcome this impact.

The current (upstream) LHWP compensation programme does not specifically address vegetable plots at the level of the village or individual household, but does provide compensatory fruit trees to displaced villages. The LHWP development programme has focussed on the upgrading of rural horticulture through establishment of seed stores and development of small-scale irrigation. Numerous NGOs are currently working successfully in the Lesotho highlands to improve village horticulture through provision of seeds and extension services.

11.4.5 Forage

Riparian zones represent valuable sources of livestock forage, especially in dry periods. No estimates of the annual production of forage grasses in riparian zones were available, and a national "rule of thumb" value of 604 kg ha⁻¹ was applied to riparian zones impacted by flow reductions, giving an overall forage production in the affected river reaches of about 4400 tonnes annually. This likely underestimates the true amounts of forage biomass available to livestock along the river reaches, which are more productive than the non-riverine areas due to more favourable moisture conditions. The value of the foregone forage was based on the current costs of hay in the highlands. If hay were used as the compensation basis then the costs of delivery would have to be added - these would be considerable for the remotely located areas along the downstream river reaches. Losses due to flow reduction were estimated at M0.5 million annually for the Treaty Scenario. Available forage biomass appears sensitive to flow releases, since a shift from the Treaty to the Fourth Scenario would reduce forage losses by three-quarters.

11.4.6 Public Health

The public health component of the IFR study predicted serious consequences of Treaty releases for the health of downstream communities, already in a poor state. Critically severe impacts were expected for diarrhoeal disease and nutritional status. The incidence of skin and eye diseases in some areas was expected to be severe. Community health deterioration was already evident in IFR Reach 2 immediately downstream of Katse Dam. The costs of mitigating the major health impacts through child immunisation, water and sanitation provision and health education in the case of the Treaty Scenario was estimated at slightly under M800,000 annually. Based on the costing approach adopted, small increments in water release (e.g., from Treaty to Fourth Scenario) would make little difference to these costs. A seven-fold increase in water releases (e.g., from Treaty to Design Limitation Scenario) would reduce costs by about one-quarter. In terms of overall project operation, therefore, additional water releases would not likely prove cost-effective in reducing community health hazards.

Public health programmes upstream of the LHWP Phase 1A structures have to date focussed on deployment of a small number of public health teams, bolstering the levels of public information on health-related issues, and on providing clean water and effective sanitation. To date about half the villages in the Katse local catchment have been provided with piped water, and about half the households and schools now have access to VIP latrines. The programme could logically be extended to the downstream areas but two major constraints would be present

- the very poor access to downstream villages and the problem of assuring equity for downstream communities, some of which are within the zone of influence of the river and others not.

11.4.7 Animal Health

Problems with livestock health associated with downstream flow reductions would relate primarily to the increased incidence of pest species such as *Simulium* and increases in already prevalent livestock diseases such as helminthiasis, horse sickness, anthrax and pulpy kidney due to increased livestock congestion and increases in disease vectors. The costs of mitigating these effects (primarily through immunisation) in the case of the Treaty Scenario were estimated at about M750,000 annually. The incidence of livestock diseases and hence the need for mitigation would be appreciably diminished through higher downstream releases (e.g., a 50% reduction from the Treaty to the Fourth Scenario). Livestock immunisation programmes are common in Lesotho, but similar constraints as in public health above would have to be taken into consideration for the downstream areas, i.e., limited access and questions of equity.

SECTION 12. MONITORING PROGRAMME

12.1 PURPOSE OF THE MONITORING PROGRAMME

Monitoring of an ecosystem is a continuing process whereby the condition of key ecosystem components are measured at repeated intervals following a disturbance and the results compared with the same kinds of data collected prior to the disturbance.

The disturbance addressed in the IFR assessment would be the ongoing and future construction of in-channel dams on rivers which would affect the flow regimes, water chemistry, and sediment and temperature regimes and, as a knock-on effect, their fauna and flora. As discussed in the preceding sections of this report, the disturbances to the rivers could be reduced by careful manipulation of flow releases from the dams (IFRs). Monitoring whether or not these flows for environmental maintenance are occurring and are achieving their stated objectives is an essential part of their implementation. Thus once a scenario has been decided upon and implemented, a monitoring programme should be implemented to:

- establish whether or not the agreed-on IFR is being released and is delivering the required flows to the IFR sites;
- verify if the objectives linked to different components of the flow regime are being achieved;
- guide adjustments of either the IFR or the objective, if the overall objective is not being achieved.

The ecosystem components (or sub-components) that would eventually be included in the monitoring programme would depend to some extent on the chosen scenario. As a specific scenario or operating regime has yet to be selected, a generic monitoring programme has been designed to include:

- all the disciplines addressed in the study, including biophysical, social, health and economic components, to the extent deemed necessary by the respective specialists;
- activities for assessing the efficacy of the different parts or aspects of the flow regime, where applicable.

This should be refined and developed in detail by the appointed monitoring team once a way forward has been decided upon. One of the most important tasks of this team will be to design a monitoring programme that will distinguish between long-term natural fluctuations in river condition and LHWP-derived change, something that it was not possible to establish a data set on in this short-term project.

The generic monitoring programme is detailed in Report No. 648-F-23.

12.2 MONITORING SITES

12.2.1 Biophysical Sites

It is suggested that the monitoring programme would make use of the same eight biophysical sites as the IFR study (Section 3.2.3), which are here referred to as monitoring sites. It is further suggested that two additional

sites be incorporated into the monitoring programme as reference sites. Potential locations for reference sites would be on the Matsoku River upstream of the headwaters of Matsoku Weir (a reference site for IFR Site 1) and on the Senqu River downstream of Mokhotlong (a reference site for IFR Sites 2, 3 and 7).

12.2.2 Social Reaches and Villages

The social reaches and villages used in the IFR study are listed in Section 3. For the monitoring programme, it is proposed that some of the eight river reaches be combined and the total number of social responses that are required be reduced. The wool sheds and clinics sampled should remain those used in the IFR study (Section 3).

12.3 MAIN FEATURES OF THE MONITORING PROGRAMME

Three tiers of monitoring are recommended for the monitoring programme, *viz.*:

- pre-construction, baseline data collection;
- post-construction, release-specific data collection;
- post-construction, long-term routine monitoring.

Summaries of the activities recommended in each tier are provided in Tables 12.1, 12.2 and 12.3, respectively.

12.3.1 Pre-Construction: Baseline Data Collection

For the most part the data collected during the IFR study are adequate as a baseline against which to assess flow-related changes in the study rivers. However, in some instances additional data collection has been recommended. The aims of this baseline data collection would be to collect:

- additional biophysical data that have been identified as being necessary to address knowledge gaps and to be able to distinguish between future flow-related changes in the rivers and other changes;
- data required to address the statistical aspects of data collection, such as the minimum number of samples required.

12.3.2 Post Construction: Release-Specific Data Collection (Biophysical Only)

The release-specific data collection should be confined to high flow events. The aims of this activity would be to collect data that would allow an assessment of whether or not the rivers are responding to different components of the flow regime in the ways predicted. For instance, the fish specialist stated that within-year high flows would provide cues for fish passage or spawning. Thus, release-specific data collection would aim at determining if fish spawning and migration did in fact occur in response to the release of such a high flow. Because of the purpose of the release-specific monitoring, it is envisaged that only biophysical data would be collected during this stage of the monitoring programme.

The data from the release-specific collection activities would be used to fine-tune IFR releases, and refine predictions of future condition, if necessary.

Since the sites closest to the LHWP dams would both be most affected by the flow changes, those sites should form the focus of the release-specific monitoring.

Table 12.1 Summary of activities required for baseline data collection.

Component	Tasks	Where Data Should Be Collected	Frequency
BIOPHYSICAL			
Hydrology	Continuous time-series stage-height data.	All gauging weirs listed in Table 3.1.	Continuous.
Hydraulics	Installation or re-installation of missing beacons, checking existing ones, and development/improvement of rating curves for all cross-sections.	All monitoring and reference sites.	Once-off.
Sedimentology	None.		
Water Quality	None.		
Riparian Vegetation	Location of vegetation zones on cross-sections.	All monitoring and reference sites.	Once-off.
	Establishment of monitoring plots.	All monitoring and reference sites.	Once-off.
	Marking of individuals of key species.	All monitoring and reference sites.	Once-off.
	Algal monitoring.	All monitoring and reference sites.	Once-off.
Macroinvertebrates	None.		
Fish	None.		
Mammals and Birds	None.		
Herpetofauna	None.		
SOCIO-ECONOMIC			
Sociology	None.		
Public Health	None.		
Animal Health	Collection and analysis of blood samples	All study wool sheds.	Annually, for two years.
	Faecal collections.	All study villages.	Twice a year.
	Collection of wool shed records.	All study wool sheds.	Annually.
	Collection of water quality data on effects of dip tanks.	All study rivers near dip tanks and animal crossings from dip tanks.	Once-off.
	Epidemiological study of internal parasites.	All monitoring sites plus reference sites.	Three times a year, for two years.
Water Supply	None.		

Table 12.2 Data collection activities for release-specific monitoring.

Component	Tasks	Frequency of collection
Hydrology	Continuous time-series stage-height data.	Continuous.
Hydraulics	Water-surface elevations and measurement/simulation of local hydraulics.	Hourly for the duration of the event.
Sedimentology	Riffle sedimentation.	Before and after an event.
Water quality	Event-related sampling of total suspended solids and nutrients.	Hourly for the duration of the event.
	Temperature monitoring.	Continuous during the event.
Fish	Monitor spawning and migration responses to within-year flood releases.	Continuous during the event, and after the event a survey for fry and larvae in the backwaters.

12.3.3 Post Construction: Long-Term Routine Monitoring

The aims of the long-term monitoring programme should be to:

- verify that the IFR releases are being made and delivering the required flow regimes to the IFR sites;
- assess the condition of the rivers for comparison with the baseline data sets;
- assess the overall efficacy of the IFRs in meeting their objectives, and to provide data that can be used as motivation for adjusting the IFRs if necessary;
- evaluate whether the parameters selected for inclusion in the monitoring programme are appropriate, and whether the list of parameters should be increased or decreased.

For some of the socio-economic components of the monitoring programme, an additional objective would be to ascertain the necessity for, and extent of, mitigation/compensation for the PAR, as recommended in Report Nos. 648-F-09 and 10.

The data collected as part of the long-term routine monitoring would provide an indication of the condition of the study rivers as a whole. These data could identify potential problems, which may then require an additional investigation of cause as part of a different sampling effort.

Table 12.3 Summary of data collection activities required for long-term data collection.

Component	Tasks	Where data should be collected	Frequency of collection for the first five years (post-construction)	Frequency of collection after the first five years (post-construction)
BIOPHYSICAL				
Hydrology	Continuous time-series stage-height data.	All gauging weirs as listed in Table 3.1.	Continuous.	Continuous.
Hydraulics	Re-surveying of cross-sections.	All biophysical monitoring sites plus Reference sites.	Every two years.	Every five years.
	Determining new hydraulic relationships.	All biophysical monitoring sites plus Reference sites.	Every two years.	Every five years.
Sedimentology	Fixed point photography.	All monitoring sites.	Once per annum.	Once per annum.
	Monitoring changes in sediment size distribution.	All monitoring sites	Once per annum.	Once per annum.
Water quality	Routine daily sampling of total suspended solids and nutrients.	All monitoring sites, plus Reference sites..	Daily.	Daily.
	Routine monthly sampling of chemical constituents.	All monitoring sites, plus Reference sites.	Monthly.	Monthly.
	WQ monitoring using loggers.	IFR Sites 3, 5 and 7.	Continuous.	Continuous.
	Temperature monitoring.	All monitoring sites, plus Reference sites.	Continuous.	Continuous.
Riparian vegetation	Monitoring changes in vertical riparian donation.	All monitoring site/s, plus Reference sites.	Once per annum in early autumn.	Once every two years early autumn.

Table 12.3 Summary of data collection activities required for long-term data collection.

Component	Tasks	Where data should be collected	Frequency of collection for the first five years (post-construction)	Frequency of collection after the first five years (post-construction)
	Monitoring plots.	All monitoring sites, plus Reference sites	Once per annum in early autumn.	Once every two years early autumn.
	Monitoring changes in key species.	All monitoring sites, plus Reference sites	Once per annum in early autumn.	Once every two years early autumn.
	Algal monitoring.	All monitoring sites, plus Reference sites.	Once per annum in early autumn.	Once every two years early autumn.
Fish	Routine fish surveys.	All monitoring sites, plus Reference sites.	Four times in the first year. Thereafter, once per annum.	Once per annum.
Macro-invertebrates	Initial intensive survey.	All monitoring sites, plus Reference sites.	Once at the end of the wet season (autumn).	Once at the end of the wet season (autumn).
	Annual monitoring of community structure.	All monitoring sites, plus Reference sites.	Once per annum (autumn).	Once per annum (autumn).
	Monitoring changes in available habitat..	All monitoring sites, plus Reference sites.	Once per annum.	Once per annum.
Birds	Population counts.	All monitoring sites, plus Reference sites.	Once per annum.	Once every five years.
SOCIO-ECONOMIC				
Sociology	Social survey.	All selected study villages.	Once a year.	Once every two years.
Public health	<i>Anopheles</i> surveys.	All selected study villages.	Once a year.	Once a year.
	<i>Bulinus</i> snail surveys.	All monitoring sites.	Once a year.	Once a year.
	Collection and collation of data from clinic records.	All study clinics.	Once a year.	Once a year.
	Maintenance of records by community record keepers.	All selected study villages.	Once a year.	Once a year.
	Water analysis for parasites and microbes.	All monitoring sites.	Once a year.	Once a year.
Animal Health	Collection and analysis of blood samples.	All study wool sheds.	Annually.	Every five years.
	Faecal collections.	All selected study villages.	Annually.	Every five years.
	Collection of wool shed records.	All study wool sheds.	Annually.	Every two years.
	Collection of water quality data on effects of dip tanks.	All study rivers near to dip tanks that have not been moved and animal crossings from dip tanks.	Every two years.	Every two years.
	Epidemiological study of internal parasites.	All monitoring sites plus reference sites.	Three times per year.	Every five years.

12.4 MANAGEMENT OF THE MONITORING PROGRAMME

The success of the monitoring programme would depend on the rigour of the data collection, and on the manner in which the data are stored and analysed. There is little point in spending time and money collecting data, if these are not collected, archived, analysed and interpreted correctly. The following recommendations are thus made:

- a Monitoring Programme Manager be appointed, who would be responsible for the co-ordination of the monitoring team and management of the programme;
- dedicated specialists be appointed to take responsibility for specific aspects of the monitoring programme;
- each member of the monitoring team keep a record of monitoring methods;
- quality control of all data and data-collection methods be applied by the monitoring team, and should be the responsibility of the Monitoring Programme Manager;
- a database be developed and housed at LHDA to store the data generated by the monitoring programme. This database should be updated annually and should allow easy access to, and interrogation of, the data. The database should link with other international databases currently being developed, which relate to IFRs and river condition. An example of such a database is the RIVERS DATABASE currently being developed by Southern Waters for the National Rivers Health Programme in South Africa.
- the monitoring programme be audited annually (ideally by an independent group of specialists referred to here as the Monitoring Steering Committee) to verify:
 - the data are being collected at the stipulated intervals;
 - the samples are being correctly analysed;
 - any laboratories undertaking sample analysis are performing their tasks correctly;
 - the data are being stored in an efficient manner, and interpreted correctly;
 - the IFR is achieving the predicted river conditions, with the predicted social and economic costs.
- the Monitoring Steering Committee consist of three members, one from each of the disciplines of sociology, ecology and water-resource management;
- the monitoring programme be refined at intervals, if necessary.

If the IFR is not meeting its objectives there should be the twin facilities of being able to revise either the IFR being released, or the desired river condition it is meant to achieve.

IFR monitoring is a new field of science world-wide. For the foreseeable future IFR monitoring programmes would be required not only to be refined on an ongoing basis using data collected as part of them, but also to take cognisance of developments and trends in the field of environmental flow monitoring. It should be the responsibility of the appointed monitoring team to be *au fait* with new thinking and design their monitoring programme accordingly.

SECTION 13. THE NEXT STEPS

13.1 RELATIONSHIP OF THE IFR TO LHWP DEVELOPMENT

The purpose of this ultimate section of the Final Report is to present salient information and observations, some of which will facilitate the decision-making process, and some aspects that will have to be considered pertinent if a credible and broadly acceptable decision on IFRs is to be reached.

This study was charged with establishing appropriate IFRs for river courses downstream of LHWP structures and for planning and initiating the monitoring programme. The contract was also required to provide recommendations for mitigation against, and compensation for, significant impacts linked with the various projects and to advise on the costs or benefits of meeting, or not meeting, the IFR in the context of current Treaty requirements.

The study has provided the following information:

- detailed descriptions of four possible scenarios for flow release regimes, including information on physical, ecological and economic consequences;
- costs of mitigation and estimates of resource losses associated with each of the four scenarios;
- estimates of system water yields for Phases 1 and 2 of the LHWP for each of the four scenarios.

In order for the IFR information from this study to be used in decision-making process, the following revenue-related information needs to be developed by the parties in Lesotho and RSA for comparison to the environmental and economic impacts of the four scenarios:

- the values of the royalties to Lesotho associated with the yields of each of the four scenarios;
- the values of hydro-generated power to Lesotho associated with each of the four scenarios;
- the costs to the RSA of reductions in yields from that available under the Treaty Scenario.

The POE has proposed a basic three-step process for moving to a consensus and decision on the IFRs to be implemented for the LHWP (POE Report 19, October 1999), namely:

Step 1: Identifying the range of an acceptable IFR

The aim of this step is to identify a rough estimate of the bulk water allocation to be made available for IFR. This will be based on the information provided by this study and determination of other costs to RSA and Lesotho specified above. These costs would be computed using models currently available to the two parties or may be assisted by outside sources. At this stage decisions are to be made by parties involved on a broad basis, considering tradeoffs between economics and environmental impacts.

Step 2: Optimisation of the preferred IFR

Once the bulk allocation of water to be made available for IFRs has been made, the optimal allocation over space and time should be made to achieve the best environmental outcome. This would require hydrological modelling of system reservoirs and allocation of water to low flows and floods for the best environmental outcome using the biophysical data collected during the course of this study.

Step 3: Formal agreement to the IFR

This stage involves of all parties agreeing on a programme of IFR releases, after consideration of the output of step 2. While this step could lead to an agreed set of IFRs, actual implementation via dam operating rules would be an additional exercise.

Thus, after an agreement has been reached on IFR releases, the reservoir operation plans need to be prepared. This is referred to as the annual plan of operation, which will provide boundaries for the operation of all completed reservoirs, including the Matsoku Diversion Weir. Releases to meet the agreed IFR however will depend on reservoir inflows and prevailing reservoir storage levels, which need to be updated on at least a weekly basis, as well as on current climate. A good IFR will mimic natural climatic conditions, providing flow variability to the rivers, and releases would be linked to flows in some undisturbed upstream point of catchment.

Establishment of an acceptable IFR is but one step in the overall management of the LHWP and cannot be effectively implemented in isolation. Decisions on IFR implementation will have to take cognisance of several inescapable facts.

- Katse Dam has been completed to a design that seeks near-maximum diversion of Malibamats'o River flows, makes minimal provision for downstream ecosystem maintenance, and has little flexibility or capacity for maintaining downstream IFRs.
- Mohale Dam and Matsoku Weir are nearing completion to designs which permit somewhat more leeway than Katse Dam in setting realistic release schedules but which are still highly constraining, e.g., Mohale Dam cannot release more than a 1:2 year flood.
- The current LHWP Phase 1 compensation programmes, embedded in the respective Environmental Action Plans, are restricted to the immediate catchments above Katse and Mohale Dams, and it would require a major revision and considerable additional expense to extend them to encompass the downstream areas in which impacts and resource losses have been shown as likely to occur.

13.2 STRATEGIC APPROACH TO OPTIMISING IFRs

The following strategies are recommended in meeting the first and second objectives of the decision-making process, i.e., in identifying a range and optimising the eventual IFRs.

- Multiple objectives are suggested, including (as a priority) matching the IFRs in as many river reaches as possible to maintain as much of the river ecosystems in as good a condition as is practically feasible.
- The upstream compensation programmes should be evaluated and those with the highest rates of success used as a basis for extension into the downstream areas. Innovative thinking will be required for programmes that have not been tested over time.

- The *status quo* is a logical starting point, i.e., Katse Dam completed and operational, Mohale and Matsoku being constructed with specific limitations on their release capacities (Annex E), and the existing Treaty in force with its downstream release stipulations and conditions for maintaining environmental quality and well-being of affected communities.
- The system under study would best be partitioned for more effective application of mitigation (permitting an adequate IFR) and planning of compensation; partitioning would optimally be achieved:
 - spatially (considering proximal and distant reaches separately since the levels of impact are different in relation to water released from upstream);
 - project-wise (initially considering Katse separate from Mohale and separate from Matsoku, and later considering feedbacks and cumulative effects);
 - scheme-wise (considering the partially-developed Phase 1 separate from Phase 2 which is still in planning).
- A step-wise procedure should be followed in reaching any decisions, commencing with steps which produce the biggest improvement from the *status quo*, i.e., the Treaty Scenario, and considering alternative steps at each stage to test whether there are better and/or cheaper approaches to reaching the same objectives.
- As a broad rule of thumb, mitigation (i.e., releasing more water through LHWP structures to reduce levels of biophysical impact and resource losses) will be much simpler to deploy and hence be more effective in the long-term than compensation in reaching similar goals of resource maintenance. It might however be more expensive due to the high optional value of released water.

13.3 NOTES FOR DECISION-MAKING PROCESS

Finally, the following items need to be borne in mind during the following stages in agreeing on IFRs in the LHWP system.

- Katse Dam is the biggest deterrent in establishing adequate IFRs throughout the Senqu system, since it controls a very large portion of the downstream flows, has little capacity for IFR releases, and the economics of Phase 1A rest heavily on near-maximal diversion of water.
- Opportunities for adequate IFRs are better in Phase 1B where Mohale Dam will be equipped with multiple-level offtakes for improving water quality of releases and can release small flood-type events. Matsoku Weir can similarly release adequate baseflows and has the capacity for releasing flood events.
- Maintenance of downstream ecosystems in good condition with reduced resource depletion will require an adequate amount of water released; maintenance of the lower Senqunyane and Matsoku rivers will require use of the full release capabilities of the respective LHWP structures.
- Extensive compensation programmes in the downstream reach areas involving community health improvement, community nutritional improvement, community forestry programmes, fisheries enhancements and agricultural development can be reduced in scope somewhat by flow releases through Phase 1B structures but cannot wholly be avoided. The best opportunities for such compensation are in the Senqunyane River downstream of Mohale Dam and in the Matsoku River downstream of Matsoku Weir due to the available access and relative proximity to ongoing Phase 1 compensation programmes.
- Phase 2 (Mashai Dam) can be developed to avoid substantial downstream impacts, and the IFR database developed in this study indicates that about a third of the river flow would be required to maintain the mid- and lower Senqu River in moderate river health.

SECTION 14. ACKNOWLEDGMENTS

LHDA Contract 648 could not have been completed without the co-operation and effort of a wide range of people from a variety of different fields. In particular, Metsi Consultants gratefully acknowledges the contributions of the following people and organisations:

- The Lesotho Highlands Development Authority.
- The LHDA Panels of Experts.
- The Lesotho Highlands Water Commission.
- The Lesotho Department of Water Affairs.
- The South African Department of Water Affairs and Forestry.
- Professor Barry Hart, Melbourne University, Australia.
- Ninham Shand Consulting Engineers, in particular Gerald Howard and Andre Greyling.
- Metsi office staff in Maseru.
- Prof. Andre Gorgens, Stellenbosch University, South Africa.
- All the individuals and companies who were involved in the project (listed under the project team).

ANNEX A: PROJECT TEAM AND STUDY MANAGEMENT

Metsu Consultants

The management team from Metsu Consultants consisted of:

- Dr. Jackie King, Project Director
- Dr. Hossein Sabet, Project Manager
- Dr. Cate Brown, IFR Process Coordinator.

Office support was provided by:

In Maseru, Lesotho

- Ms Elizabeth Mohale, Accountant.
- Ms Mary Moletsane, Receptionist/Typist.
- Mr. Maphathe Mahasane, Driver.
- Ms Esther Ratia, Office Orderly.
- Ms 'Maneo Qheku, Office Orderly.

In Cape Town, South Africa

- Ms Rosalind Townsend, Southern Waters Head Office Administration.

In Cooma, Australia

- SMEC Head Office Support.

The specialist team assembled for the study is listed in Table A.1.

Table A.1 Disciplines and specialists represented on the team.

Disciplines	Specialists	Institution/Company	Country	e-mail
Project Director	Dr J.M. King	Southern Waters	RSA	Jking@botzoo.uct.ac.za
Project Manager	Dr H. Sabet	SMEC	AUS	Smec@lesoff.co.za
IFR Process Co-ordinator	Dr C. Brown	Southern Waters	RSA	Cbrown@botzoo.uct.ac.za
Internal Advisor	Prof. B Hart	Monash Univ.	AUS	Barry.Hart@sci.monash.edu.au
IFR Data Management	Dr E. Day	Southern Waters	RSA	Rtharme@botzoo.uct.ac.za Gjh@iafrica.com Pierre@softcraft.co.za
	R. Tharme	Southern Waters	RSA	
	G. Howard	Ninham Shand	RSA	
	P. Jansens	SoftCraft Systems	RSA	
Hydrology (including yield analysis)	Dr H. Sabet	SMEC	AUS	Smec@lesoff.co.za
	S. Yance	SMEC	AUS	Silver.yance@smec.com.au
Hydraulics	A. Birkhead	Univ. Witwatersrand	RSA	Birkhead@civen.civil.wits.ac.za
	Prof. V. Alavian	RANKIN I	USA	Rankin@usit.net

Table A.1 Disciplines and specialists represented on the team.

Disciplines	Specialists	Institution/Company	Country	e-mail
Sedimentology	Prof. A. Rooseboom	Stellenbosch Univ.	RSA	Ar2@maties.sun.ac.za
Geomorphology	Dr M. Thoms	Canberra Univ.	AUS	Thoms@science.canberra.edu.au
Chemistry (water quality)	R. Skoroszewski	Senqu Consultants	RSA	Robskoro@iafrica.com
	Dr C. Palmer	Rhodes Univ.	RSA	Tally@iwr.ru.ac.za
Botany	Dr C. Boucher	Stellenbosch Univ.	RSA	Cb@land.sun.ac.za
	S. Tlale	Senqu Consultants	Lesotho	Senqu@ilesotho.com
Macroinvertebrate ecology	Dr F. de Moor	Albany Museum	RSA	Amfd@warthog.ru.ac.za
	R. Skoroszewski	Senqu Consultants	RSA	Robskoro@iafrica.com
Ichthyology (fish)	Prof. A. Arthington	Griffith Univ.	AUS	A.Arthington@mailbox.gu.edu.au
	J. Rall	Ecosun	RSA	Rall@global.co.za
	M. Kennard	Griffith Univ.	AUS	Kennard@mailbox.gu.edu.au
Wildlife ecology	Dr S. Ferreira	Private Consultant	RSA	sferreira@doc.govt.nz
Herpetofauna	Dr N. Jacobsen	Private Consultant	RSA	
Sociology	C. Boehm	Sechaba Consultants	Lesotho	Sechaba@lesoff.co.za
	Dr J. Gay	Sechaba Consultants	Lesotho	Sechaba@lesoff.co.za
	D. Hall	Sechaba Consultants	Lesotho	Sechaba@lesoff.co.za
Public Health	Dr R. Phillips	Medical Research Council	RSA	Rozett.Phillips@ac.com
Animal Health	Dr D. Phororo	Private Consultant	Lesotho	NONE
Water Supply	S. Yance	SMEC	AUS	Hywtr@smec.com.au
Economics	Dr M. Majoro	Univ. of Lesotho	Lesotho	Majoro@econ.nul.ls

LHDA Project Supervision and Participation

- Dr. Stan Hirst, Environmental Specialist.
- Mr. David Nkalai, Technical Supervisor.
- Ms Victoria Qheku, Limnologist.
- Mr. Mahase Thokoa, Biologist.
- Mr. Ndamase Matshikiza, Hydrologist.

IFR Steering Committee

A steering committee, responsible for overseeing project implementation, included representatives of:

- LHDA, Technical Services Branch (Chair).
- LHDA, Operation and Planning Branch.
- LHDA, Engineering Group.
- Lesotho Highlands Water Commission.
- Lesotho Department of Water Affairs.
- National Environmental Secretariat, Lesotho.

Panel of Experts

A three member international Panel of Experts (POE) was appointed by LHDA specifically to review LHDA Contract 648 in order to provide independent evaluation of compliance with the LHWP Treaty obligations to maintain the living standards of project-affected people and to maintain environmental amenity as far as possible.

The POE comprised the following people:

- Dr. Jane Doolan, Dept. Water Resources, Victoria, Australia.
- Prof. Tom McMahon, Professor of Environmental Hydrology, University of Melbourne, Australia.
- Dr. Mike Mentis, consultant, South Africa.

The POE interfaced with the Consultant at various stages of project implementation including the following:

- The entire POE attended the presentation of the Inception and the Task 1 Reports in January 1998.
- Dr. Mike Mentis attended the Planning Meeting in April 1998.
- The POE attended the biophysical consequences workshop in April 1999.
- Dr. Jane Doolan and Dr. Mike Mentis attended the socio-economic scenario workshop in September 1999.
- Dr. Jane Doolan and Dr. Mike Mentis attended the monitoring workshops in September 1999.
- The POE received copies of all reports produced during the project, including all internal team documents, and provided comment to the Consultant on all of these.
- Prof. Ted Scudder of the main LHDA Panel of Experts made valuable comment on the overall direction and objective of the project.

ANNEX B: TERMS OF REFERENCE**CONTRACT TITLE**

LHDA CONTRACT 648: THE ESTABLISHMENT AND MONITORING OF INSTREAM FLOW REQUIREMENTS (IFR) FOR RIVER COURSES DOWNSTREAM OF LHWP DAMS.

OBJECTIVES OF THE STUDY

The objectives of the study are:

- to assess the instream flow requirement of the Senqu, lower Senqunyane, lower Malibamats'o, and lower Matsoku Rivers;
- to assess the long-term impacts of the modified flow regimes resulting from the construction of the proposed Lesotho Highland Water Project (LHWP) dams on the ecosystems of the study rivers, and to provide recommendations for mitigation against, and compensation for, significant impacts linked with the proposed projects;
- to recommend a long-term programme to monitor the efficacy of the IFR releases, the results of which can be used to adjust the IFR as required.

TASK 1: IFR METHODOLOGY, PARAMETERS AND SITES

- (a) The study team shall review all currently accepted methodologies for determining IFR. Particular reference shall be given to the methods used for determining IFR in southern Africa and similar environments. Particular efforts shall be made towards the use of comprehensive flow regimes that cater for all river ecosystem components, such as, fish, aquatic invertebrates, water quality, riparian vegetation and the abiotic environment. The advantages and disadvantages of each method shall be identified and pertinently reviewed. The study team shall provide a description of variables to be measured for each methodology selected and provide full justification for its application on a long-term basis to the LHWP. Review and approval of the proposed methodology shall be obtained from the Panel of Experts before proceeding to the subsequent tasks.
- (b) The study team shall conduct a preliminary reach analysis of each river based on air photo interpretation, satellite imagery and any other accepted method. Classification shall take into account flow characteristics, tributary inflows, geomorphology and geology, land-use, riparian characteristics, scenic resources and other defined characteristics. Reach classification shall be confirmed by field reconnaissance.
- (c) The salient factors exerting a dominant influence on each reach, including morphological, hydrological, land-use or other factors, shall be identified and described.
- (d) Hydrological characteristics of each reach shall be described and quantified to the extent possible in each of the rivers over the full range of natural conditions including very wet years and very dry years.

- (e) Appropriate 'IFR' stretches/sites shall be selected for each river reach. These will be referred to as IFR sites or reaches. These will be described in detail and their locations marked in the field and on reference maps.

TASK 2: FIELD DATA COLLECTION

- (a) All relevant data required for the IFR determination shall be collected at each designated river stretch, under a full range of flow conditions to cover one full hydrological cycle initially.
- (b) At each river stretch suitable measurements shall be made for the following, whether they are required for immediate IFR estimation or not. It is mandatory that event-based water quality sampling be done. Such data will be compiled and utilised for long-term monitoring and assessment (and for subsequent IFR validation if required). Standard methodologies shall be utilised to the extent possible. The following data shall be collected:
- aquatic habitat characteristics;
 - macroinvertebrate assemblage structure;
 - fish population structure (with particular reference to rare or endangered species);
 - water chemistry;
 - riparian vegetation community structure and phenology;
 - wildlife;
 - threatened species;
 - incidence and abundance of known potential pest species (e.g., *Simulium*);
 - local land-use patterns;
 - community use of rivers and related socio-economic impacts;
 - water quantity/discharges;
 - flood estimations (extent of flooding and return period of different-sized floods);
 - sediment dynamics;
 - fluvial geomorphology.

Flow routing analyses shall be carried out to provide a basis for determining modified flow regimes. The Consultant shall use a computer model of river systems and dams to estimate flows at each selected river stretch.

TASK 3: IFR DETERMINATION

- (a) Based on the accepted methodology, an IFR must be determined for each of the four rivers. The Desired State of each stretch of each river shall be stated and explained. The IFR for each stretch of river will describe the recommended minimum flow regime to be maintained in each river in order to meet the Desired State. These recommended flows will encompass different seasonal baseflows to mimic natural variability and higher flows for ecological or geomorphological functioning.
- (b) A release schedule for the various dams/weirs shall be provided which will describe the recommended in-stream flows.

TASK 4: IMPACT AND RISK ASSESSMENT

- (a) Based on the data and information available from Tasks 2 and 3 and any other relevant sources, an assessment of the likely impacts to aquatic and riparian habitats and ecosystems, and any associated socio-economic systems and /or land uses of flow modification by the LHWP dams as per Treaty specifications shall be provided. The likely duration, timing, severity, spatial extent and significance of such impacts shall be indicated. The ecological and social risks to the downstream systems shall be identified and quantified to the extent possible.
- (c) Any mitigation measures and/or environmental enhancement opportunities, which may be applied to reduce impacts or enhance beneficial effects, shall be identified. Such measures should be linked to a range of releases that are less in total volume than the recommended IFR. All practical mitigation and/ or enhancement measures shall be identified and described. Any mitigation programme should be costed and a preliminary implementation programme suggested.

TASK 5: MITIGATION AND COMPENSATION

- (a) Based on the study findings and other sources of information, the Consultant will advise the Employer on the costs/benefits of meeting, or not meeting, the IFR in the context of current Treaty requirements as well as appropriate mitigation and compensation measures if it is found that the IFR cannot be satisfied.

TASK 6: MONITORING PROGRAMME AND REFINEMENT OF IFR ESTIMATIONS

The Consultant will continue with data collection for a second hydrological year to train LHDA personnel in the process that is to be continued in the long-term. A long-term monitoring programme shall be provided which shall indicate:

- parameters to be observed;
- locations of monitoring;
- timing and scheduling of field monitoring personnel;
- personnel requirements;
- equipment requirements, including any new or additional flow gauging stations required.

ANNEX C: DESCRIPTION OF THE DRIFT METHOD

DRIFT (*Downstream Response to Imposed Flow Transformations*) is explained in detail in Report No. 648-F-03. Its major steps, as used in LHDA Contract 648, are outlined below.

A. BIOPHYSICAL COMPONENTS OF THE PROCESS**1. Preparing the Hydrological Data**

- Step 1 For each IFR site, a representative 20-year data set of both present-day and historical daily flows were examined and the low and high flows separated by visual inspection.
- Step 2 In each data set, wet and dry low flow seasons were delineated.
- Step 3 Summary data were produced to describe the range of low flows in each of the seasons.
- Step 4 High flows were allocated to size classes and summary statistics produced for each class.

2. Linking the Hydrological Statistics to River Features

- Step 5 Low flow ranges were marked on cross-sectional diagrams of each site. These diagrams also showed information such as the location of zones of riparian vegetation and kinds of substrata (Figure C.1).
- Step 6 The highest level of each class of high flow was also marked on the graphics of the surveyed cross-sections.

3. Reducing Flow Levels and Recording the Biophysical Consequences

- Step 7 The reductions that could be made to the top end of the low flows with only minimal biophysical degradation of the ecosystem were described.
- Step 8 The predicted biophysical consequences of a further structured series of reductions to the top end of the low flows were described.
- Step 9 The contribution to river condition made by the high flows in each class was described.
- Step 10 Numbers of high flows in each class that could be harvested with minimal degradation to the ecosystem were identified.
- Step 11 The biophysical consequences of further reductions in high flow events were described.
- Step 12 All the consequences, each linked to its flow-reduction level, were entered into a database (Table C.1).

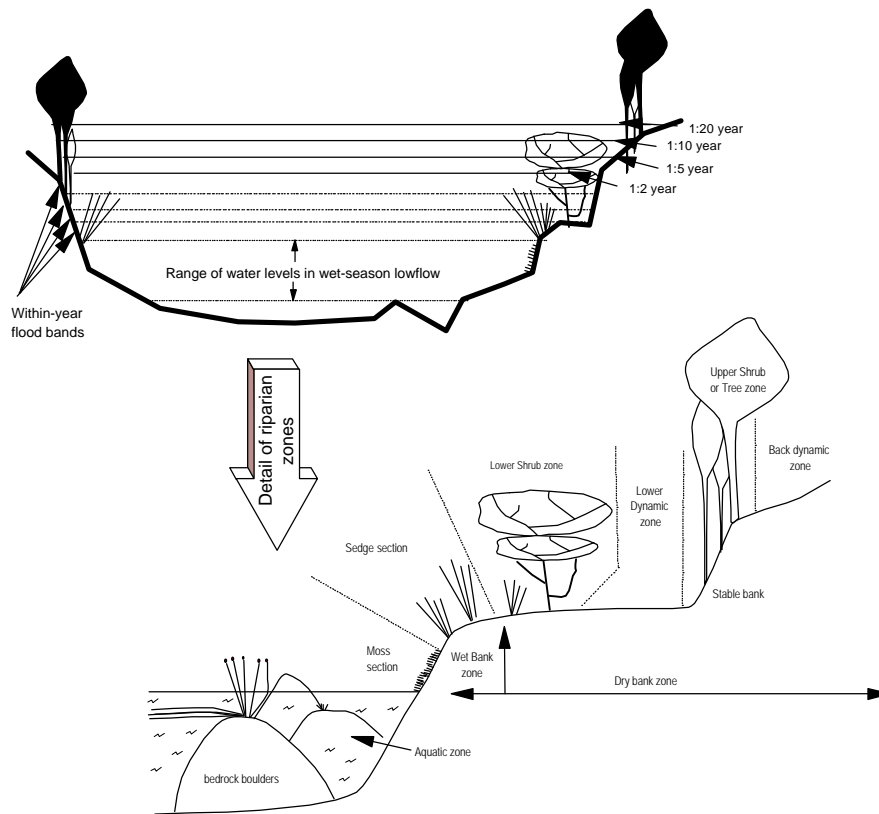


Figure C.1 Wet-season lowflow and flood water levels marked on a graphic of a surveyed cross-section, and vegetation zones linked to various levels of inundation.

4. Scenario-creation: Querying the Database to Determine the Biophysical Consequences of a Modified Flow Regime

- Step 13 Four modified flow regimes were created by combining the various flow reductions in different ways.
- Step 14 The volumes of water involved in each reduction of high flows or low flows were calculated and combined to give the overall volume required for each modified flow regime.
- Step 15 For each flow regime, the biophysical consequences of each reduction level were synthesised to create a description of the predicted river condition under that flow regime.

5. Scenario-creation: Adding Severity Ratings to Predictions of Biophysical Change

- Step 16 The severity of each of the predicted consequences was expressed as a percentage. The less the certainty of the prediction the wider the percentage range.

Table C.1 An example of the information contained in a consequence entry in the database. Sev. = severity rating. % = equivalent percent reduction or increase in abundance or occurrence.

Site	Flow Aspect	Flow Reduction Level	Component	Sub-component	Result of reduction	Sev.	%	Ecological Comment	Social Comment
IFR 1	Wet-season low flows	Level 3	Fish	Maloti Minnow	Decrease	4	60-80%	It is expected that the reduction of the low flow wet period will have a major impact on habitat quality and quantity. This change to the flow regime would significantly alter the prediction for this critically endangered species at this site, as spawning and migration cues, and availability and quality of spawning and incubation habitat would be reduced. Suitability (habitat criteria) of lateral habitats for refuge, foraging and passage of larvae and juveniles would also be reduced. Consequences would be evident in the form of changes in the abundance of larvae and juveniles and spawning success and hatching would be compromised.	Not commonly caught or utilised. Red data species.

B. SOCIO-ECONOMIC COMPONENTS OF THE PROCESS

1. Identifying the Social Impacts of Biophysical River Changes

Step 17 The extent and nature of use of river resources by riparian people, and the present state of their health and that of their domestic stock, were described and quantified. The Population At Risk (PAR) was identified.

Step 18 The predicted reductions in availability of the resources and services under any potential flow regime (Step 16) were used to estimate the social impact for each resource and each health issue.

2. Calculating the Economic Cost of Compensation and Mitigation

Step 19 An economic assessment was made of the current value of all river resources and services used by the PAR, and of compensation and mitigation costs linked to each of the four scenarios of river change.

C. CALCULATING THE IMPACT ON SYSTEM YIELD

Step 20 A yield analysis was performed using the volumes calculated in Step 14, to determine the impact on the yield of supplying a given flow regime to the downstream river.

D. OUTPUTS OF THE DRIFT PROCESS

The outputs consisted of the predicted consequences of four possible future flow regimes for the study rivers. These were referred to as IFR scenarios, and consisted of the following information.

- A *modified flow regime* for each part of each affected river. This is expressed in terms of:
 - - low flows: seasonal upper and lower discharge ranges, and monthly averages for discharge and volume.
 - - high flows: magnitude, duration and timing of flood events.

- The yields from Phase 1 and 2 dams that would result if the *modified flow regimes* were supplied to the rivers.
- The *biophysical consequences* predicted for the rivers under the modified flow regimes, including changes in:
 - channel shape and habitat availability;
 - water chemistry and temperature;
 - riparian and instream vegetation
 - macroinvertebrates;
 - fish;
 - birds;
 - herpetofauna;
 - water-dependent, terrestrial mammals.
- The *social impacts* expected as a result of the predicted biophysical changes, including impacts to:
 - use of river resources and services by the PAR;
 - public health of the PAR;
 - health of the PAR's domestic stock.
- The economic implications of the social impacts.

ANNEX D: LIST OF TITLES IN THE FINAL REPORT SERIES.

Tasks*	Report Number	Report Title	Important Contents
All	648-F-01	Executive Summary	Pending approval of brochure production
All	648-F-02	Final Report: Summary of main findings	This report
1	648-F-03	Volume 1: Terms of Reference, Study Area, Study Team and Programme of Events Volume 2: IFR Methodology	Reports on the project structure and methods used
3, 4 and 5	648-F-04	Biophysical Consequences of The Minimum Degradation Scenario	Detailed biophysical description of a 'baseline' scenario, the Minimum Degradation Scenario
3, 4 and 5	648-F-05	Biophysical Consequences of The Treaty Scenario	Detailed biophysical description of the Treaty Scenario
3, 4 and 5	648-F-06	Biophysical Consequences of The Design Limitation Scenario	Detailed biophysical description of a flow scenario imposed by design limitations of the project outflows
3, 4 and 5	648-F-07	Biophysical Consequences of The Fourth Scenario	Detailed biophysical description of a scenario with higher flows than those in the Treaty
2	648-F-08	Specialist Report – Sociology	Pilot social and anthropological survey and identification of the population at risk (PAR)
2	648-F-09	Specialist Report – Public Health	Public health data survey and assessment of the PAR, identification of links between human health and the river
2	648-F-10	Specialist Report – Animal Health	Overview and assessment of health of domestic animals of the PAR
2	648-F-11	Specialist Report – Water Supply	Water use by, and supply to, the PAR
2	648-F-12	Volume 1: Hydraulics Volume 2: Aquatic Habitat Mapping	Detailed hydraulic and aquatic habitat mapping and measurements for each IFR site
2	648-F-13	Specialist Report – Hydrology	Detailed statistics of hydrology for each river, reach and IFR site (6 Volumes)
2	648-F-14	Specialist Report – Volume 1: Sedimentology Volume 2: Geomorphology	Preliminary characterisation of the rivers and a selection of eight IFR sites
2	648-F-15	Specialist Report – Water Quality	Predictions of biophysical, flow-related changes based on a year-long rivers' research programme by a team of 19 scientists
2	648-F-16	Specialist Report – Volume 1: Riparian Vegetation Volume 2: Social Vegetation	
2	648-F-17	Specialist Report – Macroinvertebrates	
2	648-F-18	Specialist Report – Fish	
2	648-F-19	Specialist Report – Volume 1: Wildlife and Birds Volume 2: Herpetofauna	
5	648-F-20	Specialist Report – Yield Analysis	
3, 4 and 5	648-F-21	Sociological Impacts of The Four Scenarios	Predictions of social and economic impacts of four scenarios based on linkages to predicted biophysical changes
5	648-F-22	Specialist Report – Economics	Economic assessment of the current value of all river resources and services used by the PAR and the predicted change in that value under four IFR scenarios
6	648-F-23	Monitoring Protocol	Recommended monitoring programme for confirming and quantifying impacts

* refers to tasks in the terms of reference (see Annex B)

ANNEX E: WATER RELEASE FACILITIES FOR PHASES 1 & 2 PROJECTS**KATSE DAM****a. Environmental Releases**

Through a bypass in the mini-hydro power station. Intake is at 1934 m elevation (119 m below full pool level). Flows regulated by varying the opening in a sleeve valve. Maximum discharge capacity (valve 100% open) depends on reservoir elevation and ranges from $1.2 \text{ m}^3 \text{ s}^{-1}$ at 1990 m elevation (minimum pool) to $1.9 \text{ m}^3 \text{ s}^{-1}$ at 2060 m (surcharged full pool). Release as per Treaty is $0.5 \text{ m}^3 \text{ s}^{-1}$ (long-term average). Construction is complete.

b. Low-level Releases:

Through the emergency low-level outlet which is designed for emergency drawdown of the reservoir. Maximum discharge at full pool ranges from 150 to $400 \text{ m}^3 \text{ s}^{-1}$ depending on the extent of opening of the release gates, and at low pool the discharge ranges from 100 to $260 \text{ m}^3 \text{ s}^{-1}$. Intake is at 1900 masl elevation. Releases water from bottom of reservoir (= 11°C , anoxic), some reoxygenation will occur during high-pressure release. Construction is complete. Low-level releases are made each month for testing and maintenance purposes (few minutes at a time).

MOHALE DAM**a. Environmental Releases:**

Present design (as tendered): through a pipe running down left abutment of dam, pipe has eight intakes at 10 m vertical intervals, top-most intake is at 2069 masl (below normal full pool level of 2075 m), bottom-most is at 1999 m (below normal minimum pool of 2005 m). Maximum discharge capacity (using all available intakes) depends on reservoir elevation and ranges from $2.5 \text{ m}^3 \text{ s}^{-1}$ at Minimum Operating Level to $4.25 \text{ m}^3 \text{ s}^{-1}$ at Full Supply Level. Release as per Treaty is $0.3 \text{ m}^3 \text{ s}^{-1}$ (long-term average).

b. Low-level releases:

Intake at 1980 m releases water through a Howell-Bunger valve at approx. 1948 masl, maximum release c. $45 \text{ m}^3 \text{ s}^{-1}$. Released water will be c. 11°C and anoxic, some reoxygenation will occur due to jet release past cone valve.

MATSOKU WEIR**a. Environmental Releases:**

Through a 600 mm diaphragm valved outlet in the weir outlet block; elevation is 2078 masl. The valve can be set to allow a constant release independent of the upstream reservoir water level; maximum discharge is $0.65 \text{ m}^3 \text{ s}^{-1}$, Design permits base flows to take precedence over tunnel diversions. Environmental releases are not specific in the Treaty. Construction commenced 1998.

b. Scour outlet:

The 18 m weir will be provided with a gated structure located at the downstream end of the forebay, which will release water from bed level. Will be equipped with a buoyancy tank, which will cause the gate to open automatically when the tunnel intake is submerged and the reservoir level is approaching FSL. Under normal operation all flows up to *c.* $47 \text{ m}^3 \text{ s}^{-1}$ (less the environmental releases) will divert through the tunnel to Katse reservoir, flows higher than $47 \text{ m}^3 \text{ s}^{-1}$ will pass through the scour gate to downstream. Flows exceeding $96 \text{ m}^3 \text{ s}^{-1}$ will overtop the spillway. Discharges through the scour gate and/or over the spillway will occur each year in most years, the frequency and magnitude will depend on the sequence of inflows, the capacity of the reservoir, and the way in which the isolating gate in the tunnel inlet is operated. Analysis of frequency, magnitude and duration of outlet releases has not been done. The reservoir will have a small volume and released water quality is expected to be similar to that of the upper Matsoku River. Water released may have a high suspended-sediment concentration, depending on the flow released and the length of time preceding the release.

MASHAI DAM

All release facilities still to be designed. An arbitrary flow release rate of $1.5 \text{ m}^3 \text{ s}^{-1}$ was assumed for the Treaty Scenario.