

**VOLUME 2**

**AQUATIC HABITAT MAPPING**



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## EXECUTIVE SUMMARY

Studies to inform instream flow assessments (IFAs) in southern Africa centre around a number of sites along the targeted rivers. These are deemed to represent typical conditions along different parts of these rivers. Ecological inputs into IFAs on the conditions of water depth, current speed and substratum most frequently used by different species are converted to discharges flowing through the sites via hydraulic cross-sections. Thus the hydraulic cross-sections, or similar data, are a vital link between the ecologist's understanding of the river and the water manager's need to plan at the level of broad-scale volumes of flow. Typically, about three cross-sections are used per site to describe its hydraulic character. These cross-sections provide information on hydraulic conditions *at that point* for a number of measured discharges and, using these data for calibration, for any number of simulated discharges.

Ecologists undertaking IFAs have expressed the need to know more about the complete study site, so that the cross-section data can be placed into context. Habitat mapping, as used in this contract, is a tool that can be used to provide this detail. It provides a "bird's-eye view" of the complete site at a spatial resolution relevant to biological studies.

Habitat maps were drawn of each of the eight representative sites, at winter low flow. Each map consisted of a base map of the channel shape through the complete site and, within this, the distribution of eight categories of different-sized substrata. Superimposed on this was a map that detailed, within the wetted area, the distribution of 14 categories of flow types. Discharge was measured at the same time, in order to relate flow conditions to a specific percentile on the annual flow duration curve. An additional flow-type map was drawn at summer low flow, and the discharge re-measured. The maps were digitised, and ArcView GIS version 3.0 was used to produce three colour-coded maps per site: one of the substrata and two of the flow types at winter and summer low flow. Summary statistics were produced of the area of each site covered by different substrata and flow types, and by different substratum-flow combinations.

Additionally, at each site, two to four areas of distinctly different hydraulic character were delineated. Hydraulic conditions within them were measured at winter low flow, spring very-low flow and summer low flow. On each occasion in each hydraulic habitat, up to 30 sets of measurements were taken in a grid pattern, of water depth, average column velocity, substratum composition and flow type, together with any relevant ecological notes. The data were used to create frequency plots of available habitat at the three measured discharges, in terms of depth, velocity and substratum conditions. The frequency plots used the same size classes as those used by the biologists recording faunal distributions, so that information on available habitat and used habitat could be directly compared.

Changes in the proportions of available habitat could only be given for the three measured discharges. At present we are not able to simulate how the habitat maps and conditions within the hydraulic habitats would change at unmeasured discharges, and this has to be inferred.



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## PART 1: INTRODUCTION

### 1 INTRODUCTION

The objective of the habitat-mapping component of Contract 648 is to provide an overview of the IFR sites, in terms of channel morphology, the distribution of different-size substrata and the distribution of different flow types at two or more discharges.

The main sub-consultant for the work was Dr J. King of Southern Waters. Dr C. Brown of Southern Waters and Mr R. Skoroszewski and colleagues from Senqu Consultants also completed some field mapping and measurements.

### 2 OVERVIEW OF THE STUDY

#### 2.1 Terms of Reference

- Attend the Planning Meeting and initial site visit and note the extent of each IFR site chosen by the biophysical team.
- Compile site maps for all eight IFR sites, which detail the channel shape, distribution of substrata, and distribution of flow types at at least two different discharges.
- Produce the maps in an easily understood graphical form, at a level of resolution relevant to ecological studies.
- Select areas of different hydraulic character within each site, and describe them in terms of water depth, mean column velocity, substrata types and flow types at two or more discharges.
- Ensure, to the extent possible, standardisation among members of the biophysical team of terms for describing instream physical variables.
- Write a report detailing all the above aspects.
- Attend the IFR Workshop and advise the biophysical team where needed on aspects of the physical nature of the site and the changes in local hydraulics with changes in discharge.

#### 2.2 Dates of the study

Date of appointment: October 1997

Dates of field trips: December 1997; April, June, July and September 1998; January 1999.

Study culminated with report: February 1999.



**PART 2: LITERATURE REVIEWS****3 INTERNATIONAL REVIEW OF THE KINDS OF DATA USED AS INPUT ON HABITAT MAPPING IN INSTREAM FLOW ASSESSMENTS****3.1 Role of habitat mapping in management of river structure and functioning**

It is widely acknowledged that rivers as ecosystems function less efficiently when they are impacted by various unnatural physical disturbances than when in their natural state (Davies & Day, 1998). There is often then a need for costly measures to replace "silent services" (such as control of bank erosion or attenuation of floods) once naturally provided by the river ecosystem. Aquatic ecologists are aware that manipulation of river flow, for water-resource purposes, is affecting both the abiotic and biotic components of rivers (Campbell, 1986; Boon *et al.*, 1992; McCully, 1996; Davies & Day, 1998). Disturbed channels are changing in shape and size, and there are widespread reports of areas that used to support specific plant or animal species but no longer do so. Although flow-related species' disappearances are sometimes due to deterioration in water quality as a result of reduced dilution potential, loss or deterioration of physical habitat is a contributing, if not dominant, determinant in these disappearances (Statzner & Higler, 1986). Statzner & Higler, challenging well-known hypotheses on biotic distributions such as the River Continuum Concept (Vannote *et al.*, 1980), argued further that although other physical variables such as temperature are important determinants of biotic distributions, on a world-wide scale stream hydraulics is the major factor affecting biological stream zonation. From similar thinking by many groups of aquatic scientists, a new science has begun to develop, called variously hydraulic stream ecology, ecohydraulics, habitat hydraulics (Newson, 1998), or similar. This science focusses on exploring the links between physical – mainly hydraulic - conditions in rivers and biotic distributions, and on developing predictive capacity of how riverine biotas respond to changes in the physical conditions.

Many terms have been used to describe the physical environment inhabited by riverine biotas. Within the Instream Flow Incremental Methodology (IFIM) (Bovee, 1982), *macrohabitat* is described by those variables that have much the same value over some considerable length of river (i.e. several to many km), such as discharge, morphological character, temperature and water chemistry. The character of the macrohabitat reflects

changing macro-conditions, and thus biological zonation patterns, along the length of the river. *Microhabitat* is described by those variables that vary within a study site, such as substrata type, hydraulic characteristics and refuge value. The character of the microhabitat thus reflects the mosaic of micro-conditions, and thus biological distribution patterns, at any one place on a river. Others have simply used the terms habitat and biotope. If *habitat* is seen as the biotic and abiotic environment of a species (Macan, 1963), then *biotope* has become recognised as the biotic and abiotic environment of a community or species assemblage. Tharme & King (in press), for instance, recognise the biotope as describing the biological, chemical and physical attributes of the environment of a biotic community. Following from that, Wadeson & Rowntree (1998) and Newson *et al.* (1998) recognise the hydraulic biotope as excluding the biological, chemical and thermal influences, and concentrating on the flow-related aspects of living space. Wadeson (1995) describes hydraulic biotopes as spatially distinct instream flow environments characterised by specific hydraulic attributes that provide the abiotic environment in which species assemblages or communities live. This approach recognises that the boundaries of the hydraulic biotope are defined not by the biota but simply by physical aspects, and so there is no direct confirmation of their ecological relevance. Newson *et al.* (1998) view Wadeson's approach as a "top-down" one, whereby biotic use of an area is inferred from a knowledge of its physical conditions. A potentially complementary, "bottom-up" approach (Harper *et al.*, 1997) uses knowledge of the biotic distributions to identify *functional habitats*, which then act in the opposite way to Wadeson's hydraulic biotopes by inferring patterns of instream conditions. Newson *et al.* (1998) point out that we are beginning to understand the links between physically-derived hydraulic habitats and biologically-derived functional habitats, but it is not yet possible to connect each of the former to the latter. Harper *et al.* also recognise *potential habitat* as that which is actually available, as opposed to functional habitat, which is that used by a species.

Whatever the terms used, description of local hydraulic conditions within a river, that is, the physical environment available for habitation, has traditionally been done through data gleaned from surveyed cross-sections of the river. The best known application is through the IFIM (Bovee, 1982), whereby sites are selected along the river that are deemed representative of longer river reaches. Cross-sections are then placed within each site to describe typical and critical physical habitat for selected target species, whilst additional ones are placed at selected hydraulic features, in order to meet the input requirements of the hydraulic-habitat model PHABSIM (PHysical HABitat SIMulation, Bovee 1982). Each point surveyed along the cross-sections becomes the centre of a "cell" that extends half-way along the cross-section to each adjacent surveyed point, and some chosen distance upstream and downstream toward each adjacent cross-section. The study site thus consists of a grid of "cells", for each of which the hydraulic conditions can be simulated separately, to show how each changes over a range of discharges. These changing conditions can be linked to collected data on the physical conditions in which the selected species are most often found, measuring the same variables as used within PHABSIM, to reveal how changes in discharge affect their habitats.

One of the problems many ecologists encountered with this approach is that once field-collected data on physical conditions are entered into the model, intuitive understanding of the data and the river is obscured. The model's output is precise and simple, but not necessarily sympathetic to the ecologist's "feel" for the river ecosystem. Nevertheless, most authors continue to report a cross-section approach to describing hydraulic habitat (e.g. Nestler *et al.*, 1996), as this is undoubtedly an informative and cost-effective approach. Information is inevitably lost at this scale, however. For instance, Padmore (1997) reports that cross-section data typically under-represent marginal deadwaters and chutes, and fail to describe areas of slower flow among faster ones. Such shortcomings of cross-section data may be countered to some extent by the use of cross-section derived digital depth maps (GIS) to model changing hydraulic and sediment conditions. These provide greater spatial detail of flow-related changes at the studied site (Semmekrot *et al.*, 1996), and also allow limited appreciation of the wider context of the river within its landscape. However, Semmekrot *et al.*'s cross-sections were 50 m apart, and so much finer detail would have remained uncaptured.

This is of concern, because there has been increasing recognition of the importance of habitat patchiness, or physical heterogeneity, in freshwater ecosystems, and dissatisfaction with the inability to adequately describe this with cross-sectional data. The cells within the IFIM approach are described by broad extrapolation from relatively few surveyed points and do not reflect the complex mosaic of conditions present in rivers that are thought to be so important for maintaining efficient ecosystem functioning. For instance, Hildrew *et al.* (1994) point out that fine-scale, short-term biotic interactions, as well as fine-scale abiotic factors, influence longer term and spatially extensive patterns in benthic communities. Further, they state that understanding the spatio-temporal heterogeneity of physical features is the key to understanding the biological links between scales. They conclude that the two most important roles of this physical heterogeneity are to provide refugia and thus to buffer the effects of physical and chemical disturbance, and to modify the outcome of local species interactions.

Running parallel and complementary to this school of thinking is one with a geomorphological origin that points out the need to view river systems as hierarchically organised, at scales from catchment to aggregates of substratum particles (Rowntree & Wadeson, 1998; Newson *et al.*, (1998)). Rowntree & Wadeson (1998) give the levels of the hierarchy as catchment, zone, segment, reach, morphological unit and hydraulic biotope. Higher scales impose constraints on lower levels, and different geomorphological processes are characteristic of different spatial and temporal scales. Rowntree & Wadeson (1998) state that the number and type of hydraulic biotopes will differ from natural to disturbed rivers, and they and Padmore (1997) advocate the development of indices of biotope patchiness or diversity linked to changes in discharge. Such indices, and descriptions of typical biotopes and sequences, for different rivers would be important new inputs into river management and particularly into restoration projects. Newson *et al.* (1998) envisage a system of river management based on a fast assessment of hydraulic-biotope heterogeneity in order to maximise functional habitat frequency, which in turn would maximise biodiversity.

In summary, the two trains of thought lay the foundation for approaches to describing and managing physical instream habitat that incorporate, among others, the following two fundamental characteristics:

- a geomorphological hierarchy of scales, with each level from substratum particle to catchment nested in higher levels, and with each level constrained by the dictates of higher levels;
- within-site habitat mapping that reveals the complex mosaic of physical conditions at a scale relevant to studies of instream biota.

In Contract 648, the upper levels of the hierarchy of scales (catchment to reach) are reflected by the biological samples taken along the lengths of the rivers. These reveal biologically similar lengths of river. These similar lengths are correlated with the abiotic features of the river, such as altitude, slope, channel type and water chemistry, using data provided by the geomorphologists, water-quality specialists, hydrologists and hydraulic modellers. These topics are dealt with by the relevant specialists in their reports and are not considered further here.

At the lower levels of the hierarchy, that is at within-site scales, habitat maps have been created that reveal the complex mosaic of conditions at each IFR site, and these are the subject of this report.

### 3.2 Role of habitat mapping in instream flow assessments

Where the Building Block Methodology (King and Low 1998) is applied for instream flow assessments, site-specific information of physical conditions is usually provided from two main sources. Firstly, the geomorphologist completes a reach analysis of the full length of river involved in the instream flow assessment (LHDA Report No. 648-F-14 (Vol. 2)). This identifies similar stretches of river in terms of *inter alia* altitude, gradient, sediment production and transport, channel type and pattern, and information on the substrata. Each IFR site is located within a specific reach type, aiding understanding of its morphological character. A general geomorphological description of the sites is also usually provided by the geomorphologist, along with some within-site data of substrata and local hydraulics derived from the surveyed cross-sections by the hydraulic modeller.

These cross-sections form the second source of data on physical conditions at a site. They are selected jointly by the hydraulic modeller, the ecologists and the geomorphologist. They are placed to describe both representative and critical physical habitats for the biota, and to provide the necessary data for high-quality hydraulic modelling (LHDA Report No. 648-F-12). In terms

of information on habitat, they provide point-by-point data on wetted area, substrata, cover and water depth. If discharge readings are taken across a section, they also provide data on velocity distributions across the wetted area.

Although velocity distributions across such cross-sections are available for all measured discharges, they are not available for the range of discharges then simulated by the hydraulic modeller. Rather, information is usually produced, per discharge, on simulated water surface elevations (which can be converted to water depths along the cross-section) and an *average* velocity for the cross-section. Thus, information on the range of velocities pertaining at any one cross-section for any one discharge is not available through the modelling techniques presently used. One reason for this is that such precise low-flow hydraulic modelling is difficult, and the results are often of uncertain quality (King & Tharme 1994). Another short-coming of the hydraulic modelling is that its results are restricted to a description of conditions at the surveyed cross-sections. It is assumed that the cross-sections describe hydraulic conditions in any similar part of the study site. Thus, for instance, one surveyed cross-section across a riffle is assumed to describe all riffles at the site and, by implication, all riffles within the reach represented by the site. But to date, details of the rest of the site, such as how many riffles are present and where, are not usually provided.

Specialists involved in instream flow assessments have stated the need for a broader-based assessment of habitats at an IFR site. Many have said that they would like a "bird's eye view" of the sites, and to be informed of the mosaic of local hydraulic conditions present. Others would like to be able to assess the position and relevance of the cross-sections within the site as a whole, and know how velocities and depths outside these cross-sections change under different discharges. Input on these perspectives forms the habitat-mapping component of this contract.

### 3.3 Kinds of habitat-mapping data used in instream flow assessments

The concept of habitat mapping is not new. Most ecologists unconsciously perform such a mapping exercise, at least in their minds, whenever they work at a study site. There is, however, a need to develop mapping techniques both to take advantage of modern tools used in the terrestrial environment (Meixler *et al.* 1996) and to

structure more clearly how habitat is described. The process of habitat mapping described in this report was designed with this in mind.

Accepting that an IFR site is placed in its catchment context by the geomorphological specialists, the habitat-mapping component simply focusses on describing the shape, physical characteristics and local hydraulics of the sites at a scale relevant to biological studies. The approach allows the ecologists to retain a hands-on feel for the river and data as they contemplate reactions of the biota to changes in river flow. The approach is based on research being carried out at the University of Cape Town that is funded by the South African Water Research Commission (King & Schael, in prep.). This research evolved from earlier parallel research in South Africa and England which included a joint workshop on the hydraulics of physical biotopes (Rowntree, 1996). One output from that workshop was the first tentative linkage of visually assessed flow types (Padmore *et al.*, 1996) with visually assessed substratum size, to produce on paper a matrix of hydraulic conditions then named "physical biotopes". The term hydraulic biotope evolved from this, to specify more clearly the hydraulic focus of the identified areas.

Since then and in close collaboration, the English and South African geomorphologists have followed their lines of investigation on hydraulic biotopes (Newson *et al.*, (1998); Rowntree & Wadeson, 1998), and the ecologists theirs. The geomorphological perspective is at the mesohabitat scale ( $10^0 - 10^1$  m), and with an understanding *at that scale* of the ecological relevance of their units (Grundy, 1997). This scale is probably an appropriate one for most fish studies. The ecological perspective has involved compilation of comprehensive

site maps at the microhabitat scale ( $10^{-1} - 10^0$  m), of the distribution of substrata and different kinds of flow, to reveal the mosaic of local hydraulic conditions across the whole site. This scale is probably appropriate for studies of invertebrates and aquatic plants. Faunal samples then taken from a range of substrata-flow combinations have been used to assess the ecological significance of each (King & Schael, in prep.). Thus, the complementary "top-down" and "bottom-up" approaches mentioned above are being brought closer together.

In instream flow assessments, the habitat maps are used by river ecologists to understand the distribution of different kinds of physical conditions at the site, and how much of the site is suitable for specific species at any one flow. They are thus better able to assess the impacts of flow changes on these species. To further inform them of local hydraulic conditions, measurements are taken at each site within areas with distinctly different hydraulic characteristics. These reveal the depth, velocity and associated hydraulic features of the chosen areas and how these change through the seasons (after Gore *et al.*, 1992; King & Tharme 1994; Pusey *et al.* 1995; King *et al.* 1998).

The maps are also of use to specialists dealing with abiotic aspects of the sites. Geomorphologists use them to help construct projections of areas sensitive to change if discharge or sediment regimes change. Hydraulic modellers refer to the site information when constructing simulations of local hydraulic conditions over a range of discharges.

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#### 4 THE HISTORIC NATURAL CONDITION OF LESOTHO RIVERS WITH RESPECT TO IN-SITE PHYSICAL HABITAT

The historical condition of the rivers in respect of physical conditions at the sites forms part of the reviews conducted by the specialist geomorphologist and sedimentologist on the team (see LHDA Report No. 648-F-14).

## PART 3: STUDY AREA

### 5. GENERAL DESCRIPTION OF THE USE OF HABITAT MAPS IN THE STUDY AREA

#### 5.1 Purpose of the IFR sites

The sites are used to represent the full lengths of the rivers in the study area. It is assumed that each site represents a specific length of river (see Section 5.3). Data collected at a site are assumed to be reasonably representative of this length of river, unless stated otherwise.

#### 5.2 Location of the IFR sites

The sites are located at strategic places along the study rivers, at points where it is deemed that an independent flow assessment is required (Figure 5.1). Such points frequently reflect each major change in the river system; for example, sites might be chosen to represent river lengths upstream and downstream of the confluence with a major tributary. A description of the site-selection process is given in LHDA Report No. 648-F-03. The habitat-mapping specialist simply reports on the physical

characteristics of the chosen sites, and does not play a role in their selection.

#### 5.3 Extrapolation of data from IFR sites to the rest of the study area

There is no direct way of extrapolating data of the site to the greater river, as the information is site specific. However, the geomorphological Reach Analysis (LHDA Report No. 648-F-14 (Vol 2)) indicates which Reach Type each site occurs in, and the distribution and extent of that Reach Type throughout the Study Area. In a situation where enormous problems of accessibility, not to mention time and finances, make it impossible to survey every part of every river in the Study Area, the Reach Analysis provides the most realistic means of extrapolation of site data. It is thus assumed for this contract that the described conditions at any one IFR Site will be representative of average conditions throughout the Reach Type in which that site occurs.

Figure 5.1 Map showing approximate location of IFR Sites, and approximate location of constructed or proposed LHWP dams.



**PART 4: STUDY PROGRAMME****6 OVERALL PLAN****6.1 Objectives**

The objective of the habitat-mapping exercise is to describe the distributions of different sized substrata and different types of flow over the whole of each study site. Whilst the distribution of substrata is described only once, at winter low flow, the distribution of flow types is mapped both then and also at summer low flow. With the overall hydraulic character of the site described, the second objective is to delineate areas of different hydraulic conditions (here called hydraulic habitats) within the site and, in each of these, to measure variables describing local hydraulic conditions at least once each at winter and summer base flow. These hydraulic measurements are summarised per site and hydraulic habitat, using frequency plots with the variables (substratum size, mean column velocity, water depth) displayed by size class. The areas where key species occur are measured by instream biologists (fish and invertebrates) using the same variables, and the data presented in frequency plots using the same size classes. Thus, frequency plots of available habitat and used habitat can be matched, to assess the areas within a site likely to be of use to a key species.

**6.2 Conceptual model**

- Environmental macrovariables such as discharge, temperature and chemical regimes, and slope, which vary along a river, are important determinants of the overall distribution of species within a river ecosystem.
- Environmental microvariables, which vary within a site, are important determinants of species' distributions within a site. Physical habitat, or more specifically hydraulic habitat, is one of the primary determinants among these microvariables.
- If suitable hydraulic habitat does not exist at a site, a species will not occur there. If suitable hydraulic habitat does occur but the site is unsuitable in terms of macrohabitat variables, then a species will not occur there.
- Recording the availability of different hydraulic conditions at a site allows an assessment of the suitability of a site for any species, within the greater context of the suitability of the reach and zone in which the site is located.

- Within-site hydraulic conditions can be described through the two main components substrata and flow types. As both of these can be visually identified, hydraulic conditions can be mapped in a simple on-site activity.
- Substrata and flow types can be mapped separately. Additional flow-type maps can be drawn at additional different discharges, to illustrate how conditions change with discharge. Habitat maps of complete sites provide information on the mosaic of hydraulic conditions present there.
- Within-site areas that are visibly hydraulically different can be identified from the maps. Termed hydraulic habitats, they can be characterised at different discharges in terms of the hydraulic variables velocity, water depth, flow type and substratum, as well as by any relevant ecological features. These data can be matched with similar data on the conditions required by specific species, to assess habitat suitability.

**6.3 Timetable**

In the initial proposal, it was planned to map the three super sites, in terms of the distribution of different sized substrata and of flow types. After input from the rest of the biophysical team and in subsequent negotiations with the client, it was agreed to expand the study to allow all eight IFR sites to be mapped, and to allow hydraulic-habitat data to be collected at each site over at least two discharges.

- *April 1998:* Attend site-selection exercise.
- *June – August 1998:* Map channel shape and distribution of substrata at all sites, at winter low flow. On the same visit, map flow-type distributions. Measure hydraulic conditions in selected hydraulic habitats at each site.
- *September 1998:* Re-measure conditions in the chosen hydraulic habitats.
- *January 1999:* Re-map flow types at summer low flow. Re-measure conditions in the chosen hydraulic habitats.
- *January – February 1999:* Write report.

#### 6.4 Overview of activities

The eight IFR sites were visited at winter and summer low flow, and mapped in terms of their distributions of substrata and flow types. Additionally, local hydraulic conditions were measured in selected areas within the

sites, at two discharges, to develop an understanding of how local hydraulic conditions change with changes in discharge. At both winter and summer low flow, a panoramic set of photographs was taken of each complete site.

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### 7. ACTIVITIES

#### 7.1. Site delineation

##### 7.1.1. Purpose

Delineation of the areas to be mapped at each IFR site.

standardisation of pace length, and the results randomly checked by tape readings when more field workers could help.

##### 7.1.2 Field equipment and methods

The habitat-mapping specialists accompanied the biophysical specialist team into the field in April 1998, to make note of the extent of the study site selected. Sketch maps were made on site, which indicated the full extent of each site. These also showed the position of all cross-sections chosen for surveying and any useful location markers.

It is difficult to keep the long tape straight over many hundreds of meters, and to accurately map the angle of bends. The result may occasionally be that on the map the river appears more straight than in reality. However, it is felt that this does not seriously affect the overall message emanating from the exercise, which is about the general character of the site in terms of physical habitat.

#### 7.2. Measuring distances

##### 7.2.1 Purpose

To set a scale for the maps

#### 7.3 Mapping substrata

##### 7.3.1 Purpose

To describe the overall shape of the study site, and the distribution of different-sized substrata within it, as per the eight recognised categories (Table 7.1).

##### 7.2.2 Field equipment and methods

Heavy-duty tapes, 100 m and 50 m long, were used to measure distance along and across the sites. The 100 m tape was laid out in a straight line along the nearest bank. At regular intervals, usually 10 m, additional tapes were laid across the river. For ease of mapping, the cross tapes always crossed the long tape at a whole-meter number on each tape. The area delineated by the grid was mapped (see following sections) and then the tapes moved on and the process repeated. As far as possible in such rugged terrain, as the long tape was carried forward it was kept in a straight line by an observer at the starting point lining it up against a far object. At times, the tape had to be tied to a pole and flag, so that the observer could see and guide the person carrying it forward as he moved through gullies and behind banks. In some instances, for example across a wide river with strong flow and buffeting wind, tapes could not be laid. The distances were then paced, after

##### 7.3.2 Field equipment and methods

Mapping is done in the field, on graph paper. The dimensions of the site, as shown by the grid of tapes, are laid out on the paper. The scale is chosen such that the width of the river fits well into the width of the page. As the same scale is used for both axes, the complete study site will usually stretch over three to seven sheets of paper laid end to end.

The different sized substrata are mapped onto the sheets, with an ordinary lead pencil used to depict dry areas and a coloured one wet areas. In this way, the dimensions of the wetted channel show clearly. Other useful markers, such as notable trees and rocks, are also marked on the map. The exercise takes about half to two days per site, depending on site length and bed complexity.

Before leaving the river, each sheet is labelled with the river and site names, and its number in the series of maps for that site.

Table 7.1 Categories of substrata used in the mapping exercise

CATEGORY	SIZE RANGE (mm)	GUIDE LINE	φ
Mud	<0.063	finest and mud	6.5
Sand	0.063-2	coarse grit	2.0
Fine Gravel	2-16	finger nail	-2.0
Coarse Gravel	16-64	middle joint of finger length of small finger	-4.5
Small Cobble	64-128	wrist to halfway along finger	-6.5
Large Cobble	128-256	inside elbow to wrist	-7.5
Boulder	>256	inside armpits to wrists ground to waist length of tall person >length of tall person	-9.0
Bedrock		slabs of rock	-9.5

## 7.4 Mapping flow types

### 7.4.1 Purpose

To describe the distribution of flow types within each study site, as per the 14 recognised categories (Table 7.2), and how this changes with changes in discharge.

### 7.4.2 Field equipment and methods

Tracing paper is stapled over each completed substratum map. The wetted area is traced on, and then within this the areas of different flow types are drawn in. The exercise takes about one quarter to one half the time that the substrata maps take. Each sheet is labelled as for the substratum maps.

Subsequent flow maps are drawn at different discharges by using photocopies of the original substratum map and tracing a new flow-type map over it. The main area of uncertainty with this exercise is that it is sometimes difficult to assess how much the wetted area has expanded when discharges have increased. This is particularly so when the wetted edge has crept across flat,

featureless sand or bedrock. It is felt that this does not seriously jeopardise the essential message from the exercise, which is about the variety of hydraulic conditions that the site has to offer at different discharges.

Experience has shown that stable, relatively undisturbed sites are very similar from year to year, except after very big floods. In these cases, use of the initial substratum map for subsequent flow-type maps is considered to be valid. Disturbed sites may show considerable changes in bed form from year to year, invalidating use of the original substratum map. Such a problem did not occur when mapping the eight sites used in this project.

## 7.5 Characterisation of local hydraulics

### 7.5.1 Purpose

To describe, at two different discharges, local physical conditions within the site in areas of distinctly different hydraulic character.

Table 7.2 Categories of flow types used in the mapping exercise. After Rowntree *et al.* (1996), Padmore (1997), Newson *et al.* (1998), King and Schael (in prep).

FLOW TYPE	DEFINITION
Free falling (ff)	Water falls vertically without obstruction
Cascade (cas)	Water tumbling down a stepped series of boulders, large cobble or bedrock
Boil (boil)	Water forming bubbles, as in rapidly boiling water; usually below a waterfall or strong chute
Chute (ch)	Water forced between two rocks, usually large cobble or boulders; flowing fast with the fall too low to be considered free falling.
Stream (str)	Water flowing rapidly in a smooth sheet of water; similar to a chute but not forced between two bed elements
Broken standing waves (bsw)	Standing waves present which break at the crest (white water)
Undular standing waves (usw)	Standing waves form at the surface but there is no broken water
Fast riffle flow (frf)	Very shallow, fast, flickering flow, still covering most of the substrata
Rippled surface (rs)	The water surface has regular smooth disturbances which form low transverse ripples across the direction of flow
Slow riffle flow (srf)	Very shallow, slower, flickering flow, still covering most of the substrata
Smooth boundary turbulent (sbt)	The water surface remains smooth; medium to slow streaming flow takes place throughout the water profile; turbulence can be seen as the upward movement of fine suspended particles
Trickle (tr)	Small, slow, shallow flow; when occurring with small or large cobbles, flow is between bed elements with few if any submerged
Barely perceptible flow (bpf)	Smooth surface flow; only perceptible through the movement of floating objects
No flow (nf)	No water movement

### 7.5.2 Field equipment and methods

Up to four areas per site were chosen for the field measurements, based on the site maps, on acquired knowledge of the site and on an understanding of which hydraulic conditions generally tend to support different riverine biotas. In each area, up to 30 hydraulic measurements were taken in a rough grid pattern, on each visit. Variables recorded were water depth, current speed, flow type and substratum size, as well as general ecological notes such as the presence of algae. Depth and velocity readings were taken over 45 s using a top-setting wading rod, and a Marsh-McBirney *FLOMATE* Model 2000 electromagnetic flow meter. Velocities were read at 0.6 of water depth, which is an accepted measure of mean column velocity (Gordon *et al.* 1992), except where the water was deep or turbulent, where readings

were also taken at 0.2 and 0.8 depth and an average column velocity computed (Gordon *et al.* 1992).

Hydraulic-habitat characterisation of areas within each site was done on three occasions, all during base-flow conditions: June 1998, September 1998 and January 1999. At some sites data could not be gathered on all three occasions due to high flows, problems of accessibility or political unrest.

## 7.6 Digitising the maps

### 7.6.1 Purpose

To allow manipulation of the data within a Geographical Information System (GIS), and the production of informative site maps and summary statistics.

#### 7.6.2 Equipment and methods

Maps were retraced onto large sheets, in order to ensure all polygons were complete. Polygons were named by substratum or flow category. These maps were digitised, and then checked for accuracy (against the drawn maps) and scale (against the survey information provided by the hydraulic modeller), and colours were allocated to categories.

Substrata that consisted of only one class were allocated a solid unpatterned colour (e.g. areas of boulders were shown by solid purple). Mixed substrata were allocated a pattern with the base colour of the dominant (by size) particle (e.g. areas of mixed boulders and large cobbles were depicted by a purple pattern, and areas of boulders and sand by a different purple pattern). As a result, the degree of sorting of particle sizes could be registered at a glance.

Flow types were colour-coded for velocity, with fast categories depicted in various shades of red, medium categories in oranges and yellows and slow to no-flow areas in blues and greens.

Tables were produced for each site of the proportion of each category of substrata, and the proportions of different flow types under winter and summer low-flow conditions.

The surveyed cross-sections and the within-site areas used for hydraulic characterisation were located on the maps.

#### 7.6.3 Storage

The maps are stored as computer files. The original hand-drawn maps have been photocopied, and the originals will eventually reside with the client, if wished.

#### 7.6.4 Presentation

Maps are provided for all the IFR sites, together with supporting GIS-derived tables on proportions of substrata and flow types. A3-size colour maps of all sites, as per those included here, were displayed on wall charts at the April 1999 workshop. Early coloured versions of most site maps were sent to relevant members of the biophysical team in mid-1998, and they are requested to refer to these for the first reading of this document.

Frequency plots of conditions at the hydraulic habitats studied at each site are provided as figures, with depth and mean-column velocity readings shown as frequencies (i.e. number of observations). Proportions of different substrata are also shown and, where mixed substrata were recorded, the readings were allocated equally to the two or three categories present. The final allocations of substrata in the figures are given as percent occurrence.



**PART 5: DATA PRESENTATION****8 IFR SITE 1 - MATSOKU****8.1 General overview of the characteristics of IFR Site 1**

The site on the Matsoku River is situated in the upper reaches of this small tributary, upstream of a waterfall. Isolated or clumps of small trees line the banks, but there is an open canopy over about 95% of the water. The river is perennial, and winds through quite a wide valley, although the channel is constrained by banks about 1 m high. The site encompasses a bend in the river which is contained on the left bank by a tall cliff. There are mealie fields and a footpath on the right bank, but these do not appear to constitute major sediment sources to the river as the channel on that side is not heavily covered with fine sediments.

**8.2 Description of the physical habitat component at IFR Site 1**

Site visits were made in December 1997, February 1998, June 1998, September 1998 and January 1999. Mapping of channel form and substrata distribution was begun by Lepono and Raliepeng (Senqu Consultants) during February 1998, and completed by Skoroszewski in June 1998. Flow maps were drawn by King at winter low flow (June 1998) and summer low flow (January 1999). Hydraulic characterisation was done by King (June 1998), Brown (September 1998) and King & Brown (January 1999).

**8.3 Results**

Approximately 73% of the wetted area was dominated by bedrock, either with or without a cover of loose cobble and sand (Figure 8.1a, Table 8.1). Bedrock occurred along almost all of the left side of the wetted channel, and for most of the middle channel in the downstream quieter-flowing areas. There were two cobble and sand islands that were vegetated and above water at both summer and winter low flows. The riverbed around the most upstream island was mostly mixed cobble and boulder, with few

areas deemed to contain well-sorted aggregates of only one category. The right bank, nearest the fields, was lined with small cobble. The wetted width of the river was about 20 m.

At winter low flows, the channel to the right side of each island almost dried out, with scattered patches of barely moving water (Figure 8.1b). Fast-flowing areas, defined as BSW, USW, FRF and RS, (13% of wetted area – Table 8.1) were confined to the left side of the upstream island. Here, there were some fast riffle areas over boulders and cobbles and areas of rippled flow over bedrock, with more turbulent standing waves over small sills in the bedrock. At summer low flows, water flowed freely around both sides of the islands, and there were considerably more areas of fast flow (64%) (Figure 8.1c). In both winter and summer the water was clear with a slight brown colour.

Three hydraulic habitats (HH) were selected at this site (Figures 8.1b and 8.1c), and their hydraulic conditions measured on three occasions, in winter (low discharge), early spring (very low discharge) and summer (high discharge) (Figures 8.2a, 8.2b and 8.2c). HH1 was in a pool at the upstream end of the site, HH2 in the fast-flowing boulder/cobble area to the left of the upstream island and HH3 in the downstream "glide" adjacent to the downstream island.

The pool described by HH1 (Figure 8.2a) was dominated by fine substrata but with some bedrock particularly along the right bank. Velocities were always low, ranging 0-0.09 m s<sup>-1</sup> at winter low flow, and up to 0.29 m s<sup>-1</sup> at summer low flow. Water depth remained in the range 0.20-0.69 m on all three sampling occasions. Ecological notes taken on site recorded that in winter there was thin ice covering much of the pool, and that the substrata (mostly sand) were patchily covered with photosynthesising algae that was brown in appearance. Some dead leaves lay on the sand.

Figure 8.1 a Substratum map for the Matsoku River, IFR site 1, mapped at winter low flow.

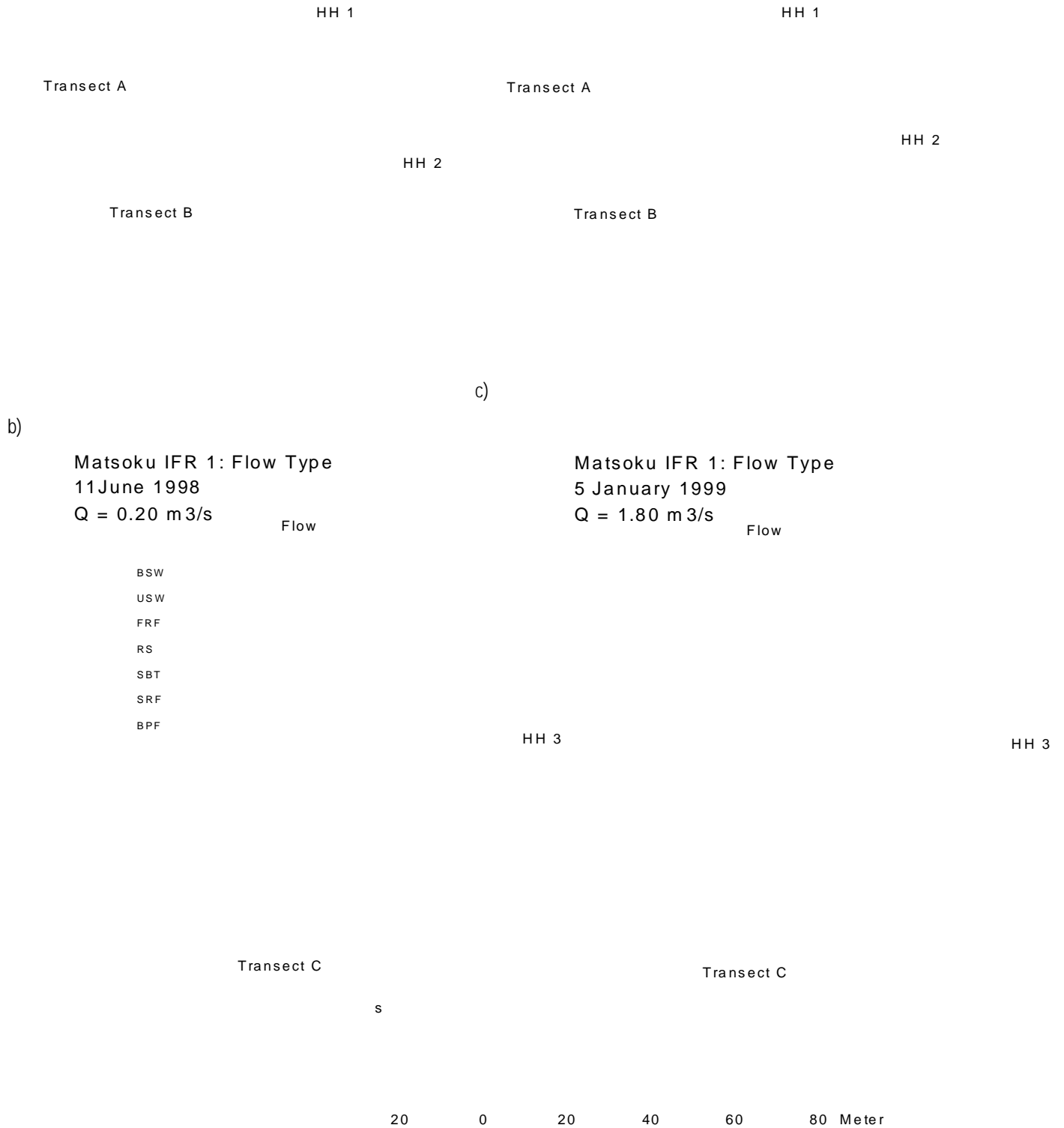


Figure 8.1: (b) Flow type map for the Matsoku River, IFR site 1, mapped at winter low flow. (c) Flow type map for the Matsoku River, IFR site 1, mapped at summer low flows.

Table 8.1 The area (m<sup>2</sup>) of wetted substrata covered by different flow types at IFR Site 1 (Matsoku) in (a) June 1998 and (b) January 1999. See text for an explanation of acronyms for substratum and flow categories.

(a) IFR 1: June 1998

FLOW TYPE	BR	BR & LC & SC	BR & SC & S	B & LC & SC	LC	LC & SC	LC & SC & S	TOTAL
BPF	678.85	4.85	397.61	265.48	118.80	7.27	178.20	1651.06
BSW	0.00	0.00	0.00	0.00	0.00	19.40	0.00	19.40
FRF	0.00	0.00	0.00	0.00	2.42	179.41	0.00	181.83
RS	176.99	13.34	0.00	0.00	0.00	168.50	0.00	358.82
SBT	1531.05	356.40	273.96	0.00	12.12	255.78	19.40	2448.70
SRF	0.00	0.00	0.00	0.00	0.00	36.37	0.00	36.37
USW	30.31	0.00	0.00	0.00	0.00	8.49	0.00	38.79
<b>TOTAL</b>	<b>2417.19</b>	<b>374.58</b>	<b>671.58</b>	<b>265.48</b>	<b>133.35</b>	<b>675.21</b>	<b>197.59</b>	<b>4734.97</b>

(b) IFR 1: January 1999

FLOW TYPE	BR	BR & LC & SC	BR & SC & S	B	B & LC & SC	LC	LC & SC	LC & SC & S	SC	TOTAL
BPF	114.44	0.00	27.42	10.73	17.88	0.00	0.00	8.35	0.00	178.82
BSW	88.22	0.00	0.00	0.00	7.15	0.00	70.34	0.00	0.00	165.71
FRF	29.80	45.30	26.23	104.91	129.94	1.19	152.59	31.00	25.04	546.00
RS	1707.13	209.82	258.69	10.73	65.57	7.15	191.93	20.27	35.76	2507.05
SBT	636.60	50.07	363.60	11.92	354.06	45.30	29.80	187.16	96.56	1775.08
SRF	45.30	0.00	0.00	0.00	139.48	143.06	0.00	3.58	4.77	336.18
USW	358.83	63.18	97.76	0.00	7.15	0.00	251.54	0.00	0.00	778.46
<b>TOTAL</b>	<b>2980.32</b>	<b>368.37</b>	<b>773.69</b>	<b>138.29</b>	<b>721.24</b>	<b>196.70</b>	<b>696.20</b>	<b>250.35</b>	<b>162.13</b>	<b>6287.29</b>

In contrast, the riffle area described by HH2 (Figure 8.2b) was shallower and faster-flowing than HH1. Velocities showed the wide range typical of riffle areas, with few slow patches and many faster areas with velocities reaching 1.49 m s<sup>-1</sup> in summer. In spring, however, before the onset of rains, velocities were confined to a narrower band of 0.01-0.39 m s<sup>-1</sup>. The substratum was dominated by cobble and boulders, with some bedrock.

HH3 was intermediate between HH1 and HH2 in its hydraulic character (Figure 8.3c). The substratum was mainly bedrock, with some fine material. The main flow pattern was smoothly gliding water, but with some faster areas in summer than in HH1. In winter, the bedrock was clean, not slippery and with no obvious algae.

Figure 8.2a Matsoku IFR 1. Hydraulic Habitat 1.

Figure 8.2b Matsoku IFR 1. Hydraulic Habitat 2.

Figure 8.2c Matsoku IFR 1. Hydraulic Habitat 3.

## 9 IFR SITE 2 – KATSE

### 9.1 General overview of the characteristics of IFR Site 2

The site on the Malibamatso River is situated approximately 2 km downstream of Katse Dam. A few isolated trees line the banks, but the water is completely exposed to the sun. Before the construction of the dam the river was perennial, and still appears to flow all year, mostly through releases from the dam. A small tributary about half way between the dam and the site augments flow during the wet season. The slopes at the site do not support crops, but are heavily used for grazing. Cattle, horses and dogs have been seen drinking at the site and angling appears common. The river channel has a low sinuosity, although the wetted channel does wind somewhat, especially during winter low flow. Most of the site consists of quietly-flowing water, with two small riffle areas in the centre of the site and an area of fast, turbulent water over a bedrock step near the downstream end of the site.

### 9.2 Description of the physical-habitat component at IFR Site 2

Site visits were made in December 1997, June 1998, September 1998 and January 1999. Mapping of channel

form and substrata distribution was initiated by King on the first visit, and completed by Skoroszewski during the 1997/98 summer. Flow maps were drawn by King at winter low flow (June 1998) and summer low flow (January 1999). Hydraulic characterisation was done by King (June 1998), Brown (September 1998) and King & Brown (January 1999).

### 9.3 Results

The site had a wide range of substrata with quite good sorting by particle size (Figure 9.1a, Table 9.1). Large parts of the wetted area were dominated by either bedrock (20%), boulders (17%), large cobble (3%) or small cobble (24%). There were some areas of mixed cobble, sand and mud. Well-sorted large cobble tended to be confined to faster flowing areas and flood channels outside the winter low-flow channel. There was a division in the character of the site, with the upstream half dominated by boulders and mixed large and small cobble, and the downstream half by bedrock and small cobble. The two small riffles marked the approximate division between the two halves. The wetted width of the channel ranged between 10 and 50 m.

Table 9.1 The area (m<sup>2</sup>) of wetted substrata covered by different flow types at IFR site 2 (Katse) in (a) June 1998 and (b) January 1999. See text for an explanation of acronyms for substratum and flow categories.

#### (a) IFR 2: June 1998

FLOW TYPE	BR	B	LC & SC	SC	M	S	TOTAL
BPF	1473.02	1802.14	1380.70	1918.53	923.14	124.42	7621.95
BSW	16.06	0.00	0.00	0.00	0.00	0.00	16.06
FRF	0.00	32.11	12.04	128.44	0.00	0.00	172.59
RS	32.11	4.01	164.56	4.01	0.00	0.00	204.70
SBT	947.23	313.07	1882.41	762.60	0.00	16.06	3921.35
SRF	0.00	0.00	20.07	64.22	0.00	0.00	84.29
USW	8.03	0.00	64.22	0.00	0.00	0.00	72.25
<b>TOTAL</b>	<b>2476.43</b>	<b>2151.32</b>	<b>3524.00</b>	<b>2877.80</b>	<b>923.14</b>	<b>140.48</b>	<b>12093.17</b>

#### (b) IFR 2: January 1999

FLOW TYPE	BR	B	LC	LC & SC	SC	G	S	M	TOTAL
BPF	774.64	1155.94	0.00	1288.39	935.18	0.00	0.00	854.91	5009.05
BSW	20.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.07
FRF	76.26	0.00	32.11	84.29	505.72	24.08	4.01	0.00	726.47
RS	373.27	120.41	56.19	686.34	441.50	0.00	0.00	0.00	1677.71
SBT	1296.41	927.16	297.01	1396.76	1176.00	0.00	140.48	8.03	5241.84
SRF	0.00	0.00	20.07	0.00	0.00	0.00	0.00	0.00	20.07
USW	8.03	12.04	0.00	68.23	20.07	0.00	0.00	0.00	108.37
<b>TOTAL</b>	<b>2548.68</b>	<b>2215.54</b>	<b>405.38</b>	<b>3524.00</b>	<b>3078.48</b>	<b>24.08</b>	<b>144.49</b>	<b>862.94</b>	<b>12803.58</b>

At winter low flow, pool-like areas at each end of the site were linked by a narrower channel of faster water (Figure 9.1b). At this time, fast-flowing areas constituted about 4% of the wetted area, whilst at summer low flow they accounted for about 20% (Figure 9.1c, Table 9.1). These proportions are considerably lower than recorded at IFR Site 1, which is in an adjacent tributary, at the same times, possibly due to the low releases from Katse Dam.

Four hydraulic habitats were selected at this site (Figures 9.1b and 9.1c), and their hydraulic conditions measured on three occasions, in winter, early spring and summer (Figures 9.2a, 9.2b, 9.2c and 9.2d). HH1 was in an area of noticeably flowing water upstream of the riffles, HH2 and HH3 were the two riffle areas and HH4 was in the downstream pool just before the bedrock step.

The substratum at HH1 consisted of gravel and large and small cobble, with a small proportion of boulders (Figure 9.2a). Velocities were in a relatively narrow band of slow to medium speed ( $0.01-0.29 \text{ m s}^{-1}$  in winter and  $0.01-0.49 \text{ m s}^{-1}$  in summer), with most of the area at the lower end of this range. Depths showed a similar narrow band and seasonal shift, ranging from  $0.01-0.39 \text{ m}$  in winter and  $0.10-0.59 \text{ m}$  in summer. The appearance of flow changed from SBT in winter to some RS in summer. In winter some rocks were clean and others coated with silt and brown algae; the situation in summer was not recorded. No readings were taken here in spring.

HH2 (Figure 9.2b) and HH3 (Figure 9.2c) were two very small areas of similar riffle flow, and may be combined for reporting purposes. Both exhibited the wide spread of velocities characteristic of riffle areas ( $0.01-0.99 \text{ m s}^{-1}$ ), and the shallow depths (mostly  $0.01-0.19 \text{ m}$ ), holding these values to some extent through the wet and dry seasons. Flow types changed from mainly FRF and RS in winter, to an increased area of these and of USW in summer. Substrata were typically gravel and cobble. The rocks were clean in winter but covered in brown algae in summer.

The downstream pool described by HH4 showed a characteristic distribution of velocities and depths. Velocities were always low, ranging from  $0.01-0.09 \text{ m s}^{-1}$  in winter low flow and reaching only to  $0.29 \text{ m s}^{-1}$  in summer. Depths ranged from shallow at the edges to  $0.89 \text{ m}$  in the centre; even at the end of the dry season, depths of up to  $0.59 \text{ m}$  remained. Flow types changed from BPF in winter to SBT in summer. All categories of substrata were present, from mud in the quietest edge areas to a bedrock sill along the left edge. Photosynthesising brown-coloured algae mixed with silt covered much of the substratum in winter, with abundant green filamentous algae over very deep silt along the quiet right bank in summer.

Figure 9.1a Substratum map for the Malibamatso River at Katse, IFR site 2, mapped at winter low flow.

b) Katse IFR site 2: Flow Type  
 10 June 1998  
 $Q = 0.19 \text{ m}^3 \text{ s}^{-1}$

c) Katse IFR site 2: Flow Type  
 4/5 January 1999  
 $Q = 1.87 \text{ m}^3 \text{ s}^{-1}$

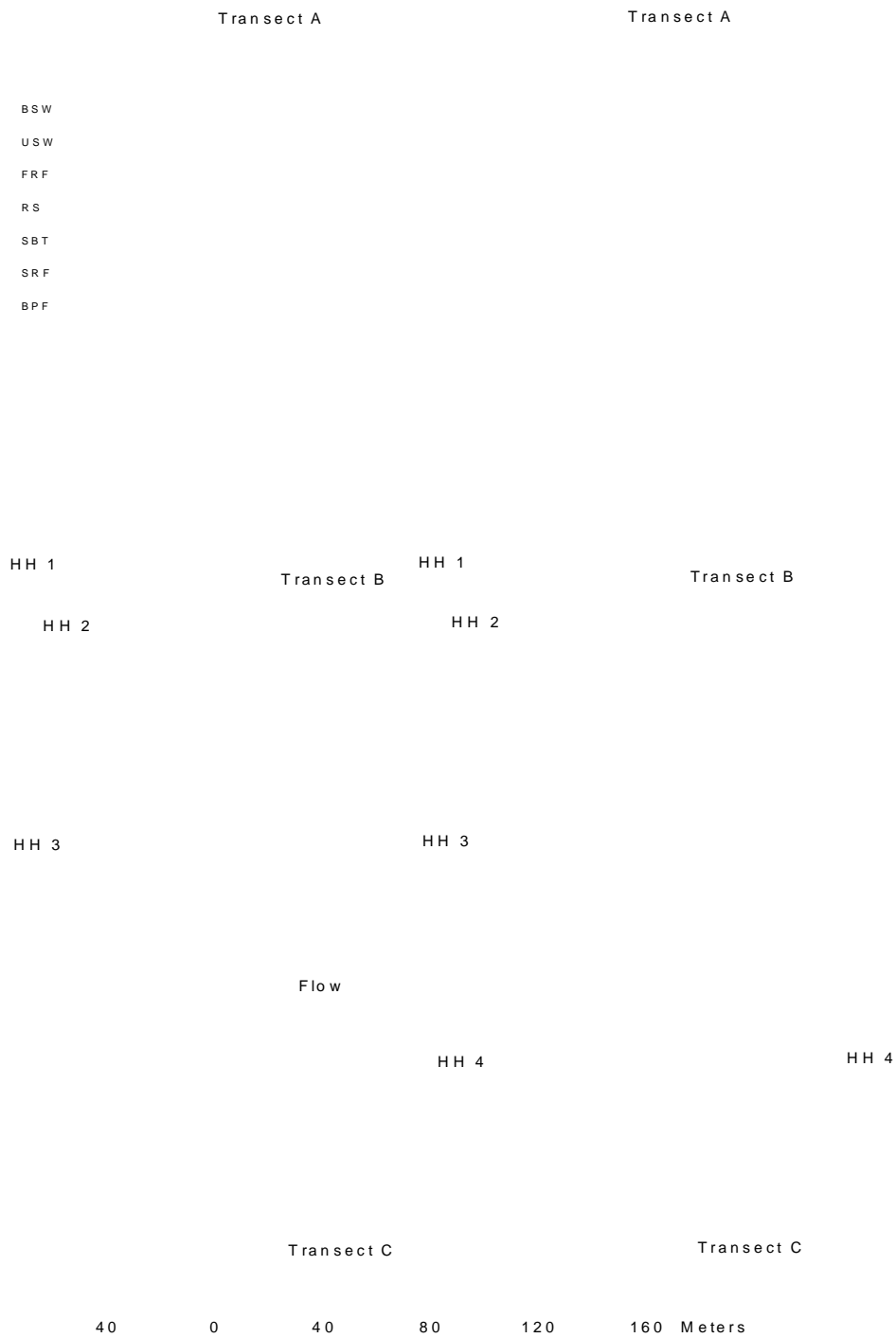


Figure 9.1 b) Flow Type map for the Malibatso River at Katse, IFR site 2, mapped at winter low flow. c) Flow Type map for the Malibatso River at Katse, IFR site 2, mapped at summer low flows.

Figure 9.2a Katse IFR 2. Hydraulic Habitat 1.

Figure 9.2b Katse IFR 2. Hydraulic Habitat 2.

Figure 9.2c Katse IFR 2. Hydraulic Habitat 3. \* = difference in vertical scale used.

Figure 9.2d Katse IFR 2. Hydraulic Habitat 4. \* = difference in vertical scale used.

## 10 IFR SITE 3 - PARAY

### 10.1 General overview of the characteristics of IFR Site 3

IFR Site 3 is on the Malibamatso River at Paray. The site is in a deep gorge and at the downstream end the river bends and then runs between almost vertical cliffs. There are meadow fields along the upstream half of the site some distance (about 50 m) from the right bank. A track runs along the right bank. A gauging weir, bridge and low-level crossing are situated upstream of the site, and a gauging tower in the middle of the site. The data loggers for water quality monitoring are near this tower. The channel is mildly sinuous through the site, though confined by the steep slopes, and bends through 90° or more just downstream of the site.

### 10.2 Description of the physical-habitat component at IFR Site 3

Site visits were made in December 1997, June 1998, September 1998 and January 1999. Mapping of channel form and substrata distribution was initiated by King and Oheku (LHDA) on the first visit, and completed by Skoroszewski in June and September 1998. Flow maps were drawn by King at winter low flow (June 1998) and summer low flow (January 1999). Hydraulic characterisation was done by King (June 1998), Brown (September 1998) and King & Brown (January 1999).

### 10.3 Results

IFR Site 3 was the longest of the eight, chosen in order to describe as many channel features as possible for different specialists. The substrata were not well sorted, with few areas of a single substratum category (Figure 10.1a). The site may be roughly divided into four substratum areas: an upstream area dominated by cobbles; an upper central area dominated by sandy deposits; a lower central area consisting mostly of bedrock but with a deep boulder and sand channel near the left bank; and a downstream area characterised by boulders mixed with various finer substrata, which gradually gives way to cobble then sand. Overall, bedrock and mixed bedrock categories accounted for 16% of the wetted area, boulder and mixed boulder categories 29%, large cobble and mixed cobble and sand area 30%, gravel and mixed gravel and sand areas 6%, sand 19% and mud <1% (Table 10.1). Of these, only 40% were in single-category areas, compared with Katse, where 72% were, and Matsoku, where 55% were. The wetted width of the

channel ranged from about 15 to 60 m.

Slow flows - mostly SBT - characterised the site during winter low flow (Figure 10.1b), covering 77% of the wetted area (Table 10.1). Of the faster categories, the largest component was FRF (7%), which is shallow flickering flow, usually over cobble. The situation at summer low flow was 46% slow-flow areas (Figure 10.1c), with the major component of the faster flows being RS (40%) which represents a deeper smoother flow than FRF. Three hydraulic habitats were selected at this site (Figures 10.1b and 10.1c), and their hydraulic conditions measured on three occasions, in winter, early spring and summer (Figures 10.2a, 10.2b and 10.2c). HH1 was at the downstream end of a large grassy island near the upstream end of the site, in a mixed fast-flowing area, HH2 was in a pool-like section in mid-site near the gauge tower, and HH3 was in a downstream bedrock/boulder rapid that marked the beginning of the deep boulder and sand channel.

HH1 contained most substratum categories, with higher proportions of gravel and cobble (Figure 10.2a). Velocities were characteristic of riffle areas, being over the wide range 0.01-0.79 m s<sup>-1</sup> in winter and 0.01-1.49 m s<sup>-1</sup> in summer. There was a marked trend toward the lower velocity classes 0-0.19 m s<sup>-1</sup> in early spring. Depths were in the shallow range 0.01-0.39 m in both winter and summer. Flow types changed from mostly RS in winter to mostly BSW, USW and FRF in summer.

HH2, in the pool-like area upstream of the tower, consisted mostly of sand and gravel substrata, with isolated cobbles and patches of bedrock (Figure 10.2b). The depths were in much the same range as for HH1, but velocities were lower (up to 0.39 m s<sup>-1</sup> in winter and 0.49 m s<sup>-1</sup> in summer), reflecting the wider channel here. The flow type was SBT in both winter and summer.

HH3, in the deep channel, had a substratum dominated by large cobble, boulder and bedrock (Figure 10.2c). Further downstream, as this channel widened, sand also became a major component of the substratum. Velocities reflected the large-size bed particles, with much hydraulic cover and therefore low velocities, mixed with very high velocities (up to 1.99 m s<sup>-1</sup> measured; faster flows were present but unmeasurable). Depths similarly ranged from shallow to 0.89 m and more). Flow types were BSW and RS in winter, changing to a large area of USW in summer.

Table 10.1 The area (m<sup>2</sup>) of wetted substrata covered by different flow types at IFR Site 3 (Paray) in (a) June 1998 and (b) January 1999. See text for an explanation of acronyms for substratum and flow categories.

(a) IFR 3: June 1998

FLOW TYPE	BR	BR & SC & S	B	B & LC & SC	B & SC & G	B & G	B & S	LC	LC & SC	LC & SC & S	G	G & S	S	M	TOTAL
BPF	1276.51	444.63	0.00	28.69	0.00	0.00	932.28	0.00	14.34	0.00	114.74	0.00	258.17	0.00	3069.37
BSW	57.37	0.00	0.00	0.00	57.37	0.00	57.37	0.00	28.69	0.00	0.00	0.00	0.00	0.00	200.80
FRF	0.00	43.03	0.00	0.00	114.74	0.00	0.00	0.00	1678.11	0.00	0.00	0.00	0.00	0.00	1835.88
NF	0.00	315.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	315.54
RS	0.00	71.71	0.00	0.00	0.00	0.00	86.06	143.43	243.83	0.00	0.00	0.00	43.03	0.00	588.06
SBT	1104.40	1305.20	315.54	2165.77	674.11	172.11	2079.71	1434.28	2768.17	1663.77	516.34	516.34	4833.53	157.77	19707.05
SRF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	114.74	0.00	0.00	0.00	0.00	0.00	114.74
USW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.69	0.00	0.00	0.00	0.00	0.00	28.69
<b>TOTAL</b>	<b>2438.28</b>	<b>2180.11</b>	<b>315.54</b>	<b>2194.45</b>	<b>846.23</b>	<b>172.11</b>	<b>3155.42</b>	<b>1577.71</b>	<b>4876.56</b>	<b>1663.77</b>	<b>631.09</b>	<b>516.34</b>	<b>5134.73</b>	<b>157.77</b>	<b>25860.12</b>

(b) IFR 3: January 1999

FLOW TYPE	BR	BR & SC & S	B	B & LC & SC	B & SC & G	B & G	B & S	LC	LC & SC	LC & SC & S	G	G & S	S	M	TOTAL
BPF	799.38	828.45	0.00	0.00	0.00	130.81	0.00	130.81	72.67	29.07	0.00	0.00	14.53	0.00	2005.71
BSW	0.00	0.00	87.21	377.89	0.00	0.00	29.07	0.00	58.14	0.00	0.00	0.00	0.00	0.00	552.30
CASCADES	0.00	0.00	0.00	14.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.53
FRF	0.00	0.00	0.00	290.68	0.00	0.00	58.14	0.00	1060.99	43.60	0.00	0.00	72.67	0.00	1526.09
RS	392.42	857.51	348.82	1017.39	726.71	0.00	2281.86	406.96	2979.50	828.45	0.00	392.42	726.71	0.00	10958.74
SBT	944.72	392.42	276.15	0.00	116.27	72.67	784.84	1119.13	523.23	436.02	697.64	450.56	4389.31	232.55	10435.51
USW	0.00	14.53	72.67	581.37	14.53	0.00	508.70	0.00	261.62	188.94	0.00	0.00	43.60	0.00	1685.96
<b>TOTAL</b>	<b>2136.52</b>	<b>2092.92</b>	<b>784.84</b>	<b>2281.86</b>	<b>857.51</b>	<b>203.48</b>	<b>3662.60</b>	<b>1656.89</b>	<b>4956.14</b>	<b>1526.08</b>	<b>697.64</b>	<b>842.98</b>	<b>5246.83</b>	<b>232.55</b>	<b>27178.85</b>

Figure 10.1a Substratum map for the Malibatso River at Paray, IFR site 3, mapped at winter low flow.



Figure 10.2a Paray IFR 3. Hydraulic Habitat 1. \* = difference in vertical scale used.

Figure 10.2b Paray IFR 3. Hydraulic Habitat 2. \* = difference in vertical scale used.

Figure 10.2c Paray IFR 3. Hydraulic Habitat 3. \* = difference in vertical scale used. Arrow = plus higher size classes that could not be measured

## 11 IFR SITE 4 – SEHONGHONG

### 11.1 General overview of the characteristics of IFR Site 4

IFR Site 4 is situated on the Senqu River in a wide valley with surrounding high mountains. Extensive sandy flats occur on the left bank, whilst the right channel edge is confined by banks about 2 m high. The dominant feature of the site is in its centre, where the river swerves to the left, passes through a large riffle area and swings right around an extensive boulder, cobble and sand bar. Upstream of the riffle the river is pool-like, and downstream it grades from very shallow and slow over the bar edge to deep and slightly faster against the cliff-constrained left bank. There are no fields in the valley bottom, but some are present at the top of the gorge, where there also is a village. There is extensive gully erosion on the slopes above the site. Animals are brought to water at the river, and there is a fairly busy foot-track descending down the gorge to cross the river on a footbridge just upstream of the site.

### 11.2 Description of the physical-habitat component at IFR Site 4

Site visits were made in December 1997, June 1998, September 1998 and January 1999. Mapping of channel form and substrata distributions was done by Skoroszewski in June 1998. Flow maps were drawn by Skoroszewski at winter low flow (June 1998) and by King at summer low flow (January 1999). Hydraulic characterisation was done by King (June 1998), Brown (September 1998) and King & Brown (January 1999).

### 11.3 Results

Most of the wetted channel had a sand substratum (Figure 11.1a). There were extensive boulder and cobble areas associated with the mid-site riffle, with two small areas of well-sorted large cobble. Downstream of the riffle, the wetted-edge/boulder bar interface had a substantial layer of mud over the sand. Overall, boulder or boulder and cobble covered 5% of the wetted area, large cobble or mixed cobble and sand 18%, gravel 1% and sand 76% (Table 11.1). Eighty percent of the site was represented by single categories of substratum. Apart from the riffle area, the wetted channel was about 60 m wide, and the water flowed smoothly.

Slow-flow areas, mostly SBT, dominated the site (Figure 11.1b), constituting 85% of the wetted area in winter

(Table 11.1) and 73% in summer. Faster flow was confined to the central riffle, where BSW (4% of total site) and FRF (6%) were the major flow types. In summer, FRF gave way to the more turbulent BSW across the whole of the riffle (BSW - 9% of total site), whilst RS became the most common fast category (14%) due its appearance in the downstream run.

Four hydraulic habitats were selected at this site (Figures 11.1b and 11.1c), and their hydraulic conditions measured on three occasions, in winter, early spring and summer (Figures 11.2a, 11.2b, 11.2c and 11.2d). HH1 was immediately upstream of the riffle, in smooth-flowing water, HH2 and HH3 were in the riffle area, and HH4 was in the downstream run skirting the boulder bar.

HH1 contained large substratum elements, mostly largely covered or at least heavily embedded in sand and mud (Figure 11.2a). Velocities were low in winter ( $<0.19 \text{ m s}^{-1}$ ) but increased appreciably in summer (up to  $0.79 \text{ m s}^{-1}$ ). Further upstream, in the quieter waters at the top end of the site, velocities taken at a discharge transect were about the same in winter but lower in summer, within the range ( $0.10\text{-}0.61 \text{ m s}^{-1}$ ). Measurements were not taken in this HH in spring, but winter and summer depths were mostly in the range  $0.30\text{-}0.79 \text{ m}$ . At the upstream discharge transect, depths were up to  $0.83 \text{ m}$  in winter and  $0.98 \text{ m}$  in summer. The flow type was SBT in both seasons.

HH2 and HH3 were in adjacent areas of the riffle, with HH2 tending to have deeper water and more turbulent flow (Figure 11.1b). Both were dominated by mixed cobble and boulder substrata, with no bedrock or fines (Figures 11.2b and 11.2c). Velocities, typically for riffles, covered a wide range, up to  $0.99 \text{ m s}^{-1}$  in winter and  $1.99 \text{ m s}^{-1}$  in summer, with HH2 usually tending toward slightly higher values than HH3. Similarly, the upper limit of depths was higher for HH2 than for HH3, but with maxima over the whole area of  $0.49 \text{ m}$  in winter,  $0.29 \text{ m}$  in spring and  $0.59 \text{ m}$  in summer. Flow types in winter were mainly BSW in HH2 and FRF in HH3, and BSW in both areas in summer.

HH4 was in the downstream area with gliding flow. Although there were scattered large bed elements, particularly near the left bank cliffs, the dominant substrata were mud, sand and, to a lesser extent, gravel (Figure 11.2d). Velocities decreased sharply toward the end of the dry season, from a maximum that could be measured

(because of depth) of 0.79 m s<sup>-1</sup> in winter to one of 0.19 m s<sup>-1</sup> in spring, before recovering again in summer. Depths on all sampling occasions were shallow on the right edge against the boulder bar to too deep to stand in

on the left side. This deep tongue of water had smooth gliding flow (SBT) in winter, increasing in speed to RS in summer. The inner half of the curve had flow-type BPF in summer, and increased in speed to SBT in summer.

Table 11.1 The area (m<sup>2</sup>) of wetted substrata covered by different flow types at IFR Site 4 (Sehonghong) in (a) June 1998 and (b) January 1999. See text for an explanation of acronyms for substratum and flow categories.

(a) IFR 4: June 1998

FLOW TYPE	B	B & LC & SC	LC	LC & SC & S	G	S	TOTAL
BPF	0.00	0.00	0.00	372.42	82.76	3708.26	<b>4163.44</b>
BSW	0.00	171.89	73.21	588.87	0.00	0.00	<b>833.96</b>
CH	70.03	76.39	0.00	9.55	0.00	15.92	<b>171.88</b>
FRF	0.00	203.72	0.00	989.93	0.00	19.10	<b>1212.74</b>
RS	0.00	162.34	108.22	3.18	0.00	6.37	<b>280.11</b>
SBT	0.00	31.83	190.98	1247.76	79.58	12468.03	<b>14018.18</b>
SRF	0.00	155.97	0.00	47.75	0.00	0.00	<b>203.72</b>
USW	3.18	226.00	70.03	92.31	0.00	25.46	<b>416.98</b>
<b>TOTAL</b>	<b>73.21</b>	<b>1028.13</b>	<b>442.44</b>	<b>3351.76</b>	<b>162.34</b>	<b>16243.13</b>	<b>21301.01</b>

(b) IFR 4: January 1999

FLOW TYPE	B	B & LC & SC	LC	LC & SC & S	G	S	TOTAL
BPF	0.00	0.00	0.00	342.84	0.00	1450.95	<b>1793.79</b>
BSW	0.00	707.11	122.44	1092.80	0.00	0.00	<b>1922.36</b>
CH	3.06	125.50	0.00	18.37	0.00	0.00	<b>146.93</b>
FRF	0.00	88.77	0.00	3.06	0.00	0.00	<b>91.83</b>
RS	0.00	128.57	128.57	358.15	48.98	2268.26	<b>2932.51</b>
SBT	0.00	6.12	0.00	1187.70	146.93	12483.07	<b>13823.82</b>
USW	0.00	6.12	198.97	287.74	0.00	128.57	<b>621.40</b>
<b>TOTAL</b>	<b>3.06</b>	<b>1062.19</b>	<b>449.98</b>	<b>3290.66</b>	<b>195.91</b>	<b>16330.84</b>	<b>21332.63</b>

Sehonghong IFR Site 4:  
Substrata  
6 January 1999

Figure 11.1a      Substratum map for the Malibamatso River at Sehonghong, IFR site 4, mapped at winter low flow.

c)

b) SPECIALIST REPORT  
AQUATIC HABITAT MAPPING

Sehonghong IFR site 4:  
Flow Type  
6 January 1999  
Q = 11.91 m<sup>3</sup> s<sup>-1</sup>

Sehonghong IFR site 4:  
Flow Type  
8 June 1998  
Q = 3.56 m<sup>3</sup> s<sup>-1</sup>

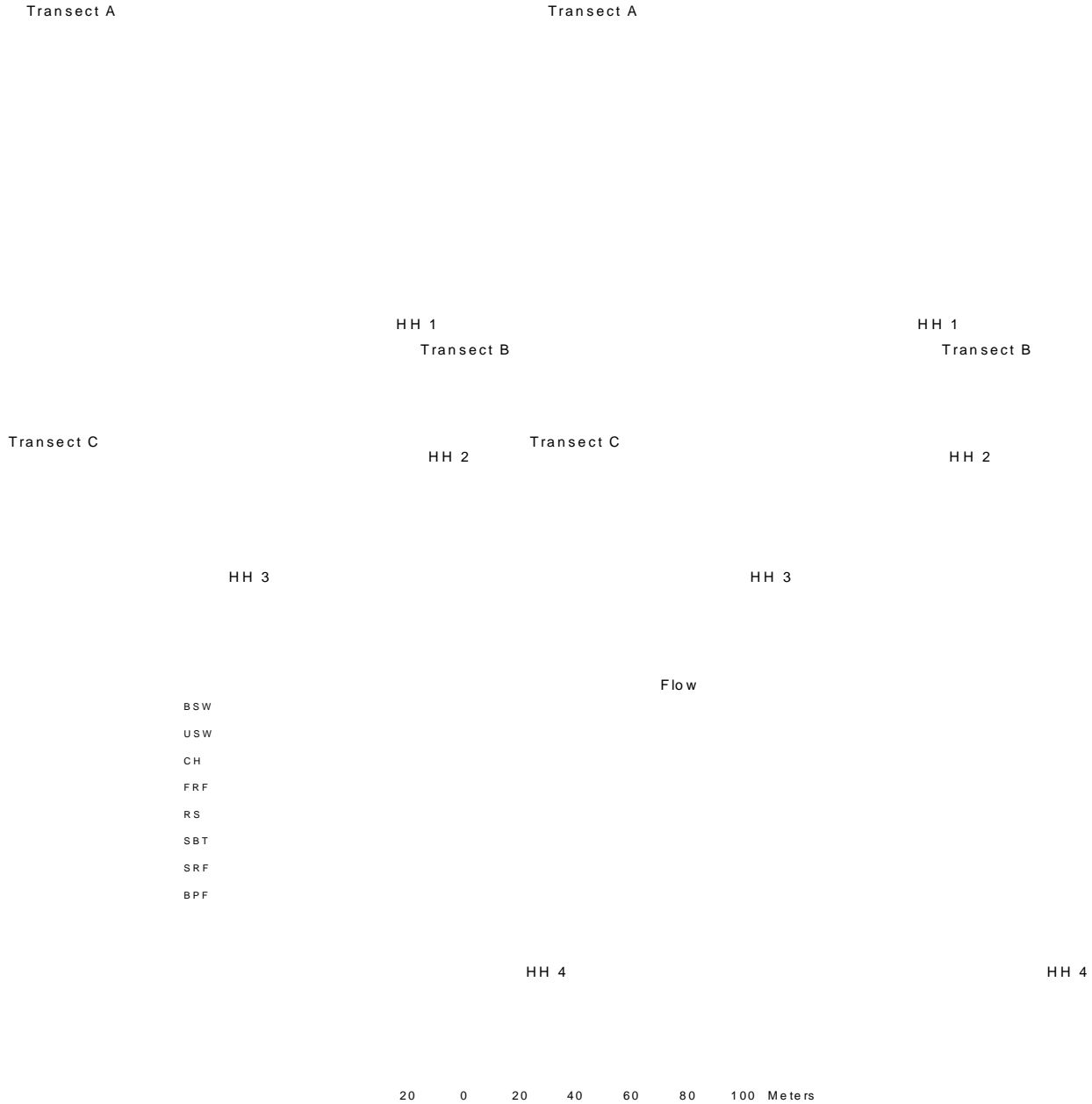


Figure 11.1 b) Flow type map for the Malibatso River at Sehonghong, IFR site 4, mapped at winter low flow. c) Flow type map for the Malibatso River at Sehonghong, IFR site 4, mapped at summer low flow.

Figure 11.2a Sehonghong IFR 4. Hydraulic Habitat 1.

Figure 11.2b Sehonghong IFR 4. Hydraulic Habitat 2.

Figure 11.2c Sehonghong IFR 4. Hydraulic Habitat 3.

Figure 11.2.d Sehonghong IFR 4. Hydraulic Habitat 4. Arrow = plus higher size classes that could not be measured.

## 12 IFR SITE 5 – WHITEHILLS

### 12.1 General overview of the characteristics of IFR Site 5

The site is on the middle reaches of the Senqu River, in a wide valley with surrounding high mountains. It has many similarities with Site 4, as the river flows smoothly to a central left-right bend which is a riffle-rapid, and then flows on smoothly around an extensive cobble and boulder bar on a wide right-hand curve. Upstream of the riffle-rapid, the river is pool-like, with sand banks approximately 1 m high on the left edge. On this side there is also a wide, elevated sandy flood channel.

### 12.2 Description of the physical-habitat component at IFR Site 5

Two site visits were made in September 1998 and one in January 1999. Mapping of channel form and substrata distribution was done by Skoroszkeski on the first visit. Flow maps were drawn by Skoroszewski at spring low flow (September 1998) and by King at summer low flow (January 1999). Hydraulic characterisation was done by Brown (September 1998) and King & Brown (January 1999).

### 12.3 Results

In terms of substrata, the site could be divided into two (Figure 12.1a). The upstream smoothly-flowing area had a sand substratum, with a line of boulders along the right bank of the macro-channel. The central riffle area and downstream run were dominated by boulder and cobble mixes, with virtually no sand. Overall, boulder and boulder/cobble mixes accounted for about 30% of the wetted area at summer base flow (Table 12.1) and sand, gravel and mud for the remaining 70%. Single categories of substrata constituted 72% of the wetted area.

Slow-flow categories - mostly SBT - were characteristic of the site, covering more than 85% of the wetted area in spring (Figure 12.1b, Table 12.1), and decreasing to 69% in summer. As with the fast-flow areas at Sehonghong, in winter FRF (7%) covered much of the riffle, whilst the downstream run had some RS (6%). In summer, FRF

(<1%) had given way to BSW (14%) and USW (7%) over much of the riffle area (Figure 12.1c), whilst the amount of RS had stayed much the same (7%). Outside the riffle area, the wetted width was about 60 m above the riffle and 25 m downstream of it.

Four hydraulic habitats were selected at this site (Figures 12.1b and 12.1c), and their hydraulic conditions measured on two occasions, in early spring and summer (Figures 12.2a, 12.2b, 12.2c and 12.2d). HH1 was in the upstream smooth-flowing area, HH2 and HH3 were in the riffle area, and HH4 was in the downstream run.

HH1 had a substratum of mostly sand and mud (Figure 12.2a). Velocities were in a narrow band, being low in spring ( $< 0.19 \text{ m s}^{-1}$ ), but higher in summer (in the range  $0.40 - 0.69 \text{ m s}^{-1}$ ). There was a much wider spread of depths in both seasons, with the size class up to 1.99 m represented and flow-type SBT predominating in both seasons.

HH2 and HH3 were in the riffle area (Figures 12.1b, 12.2b and 12.2c), with HH2 tending to be somewhat faster and deeper. All the FRF recorded in spring was over HH2, whilst HH3 had mostly RS at that time. Both areas had BSW in summer. There were areas that could not be measured in both spring and summer, particularly in HH2, and so the upper limit of depth and velocity conditions cannot be given. Velocity readings up to  $0.69 \text{ m s}^{-1}$  were taken in spring, and up to  $1.99 \text{ m s}^{-1}$  in summer. Depths up to 0.69 m were recorded in spring but the deeper waters could not be entered in summer due to high velocities.

HH4 was in the downstream run. The flow type was mostly SBT in spring, but speeded up to USW and RS in summer. Substrata recorded during hydraulic characterisation were large cobble and sand, although boulders were also recorded during mapping. Again, the water was too deep and fast for measurements on a grid pattern, and very few, basically unrepresentative readings were taken from edge areas (Figure 12.2.d).

Table 12.1 The area (m<sup>2</sup>) of wetted substrata covered by different flow types at IFR Site 5 (Whitehill) in (a) September 1998 and (b) January 1999. See text for an explanation of acronyms for substratum and flow categories.

(a) IFR 5: September 1998

FLOW TYPE	B & LC & SC	S	TOTAL
BPF	270.21	1002.67	<b>1272.88</b>
FRF	618.58	24.56	<b>643.14</b>
RS	531.48	14.52	<b>546.00</b>
SBT	1155.64	5263.47	<b>6419.12</b>
SRF	62.53	0.00	<b>62.53</b>
USW	52.48	2.23	<b>54.71</b>
<b>TOTAL</b>	<b>2690.91</b>	<b>6307.46</b>	<b>8998.37</b>

(b) IFR 5: January 1999

FLOW TYPE	B	B & LC & SC	B & S	SC	G & S	S	M	TOTAL
BSW	0.00	1480.56	154.09	0.00	56.95	154.09	2.23	<b>1847.91</b>
FRF	0.00	127.29	0.00	0.00	0.00	0.00	0.00	<b>127.29</b>
RS	138.45	620.81	0.00	0.00	26.80	149.62	1.12	<b>936.80</b>
SBT	41.31	583.96	0.00	120.59	14.52	8511.55	117.24	<b>9389.17</b>
USW	178.65	678.87	15.63	0.00	0.00	211.03	132.87	<b>1217.05</b>
<b>TOTAL</b>	<b>358.42</b>	<b>3491.49</b>	<b>169.72</b>	<b>120.59</b>	<b>98.26</b>	<b>9026.29</b>	<b>253.46</b>	<b>13518.22</b>

Whitehill IFR Site 5:Substrata  
17 September 1998

Figure 12.1a Substratum map for the Malibamatso River at Whitehills, IFR site 5, mapped at winter low flow.

c)

SPECIALIST REPORT  
AQUATIC HABITAT MAPPING

Whitehill IFR site 5: Flow Type  
17 September 1998  
Q = 1.90 m<sup>3</sup>s<sup>-1</sup>

Whitehill IFR site 5:

Flow Type  
7 January 1999  
Q = 19.0 m<sup>3</sup>s<sup>-1</sup>

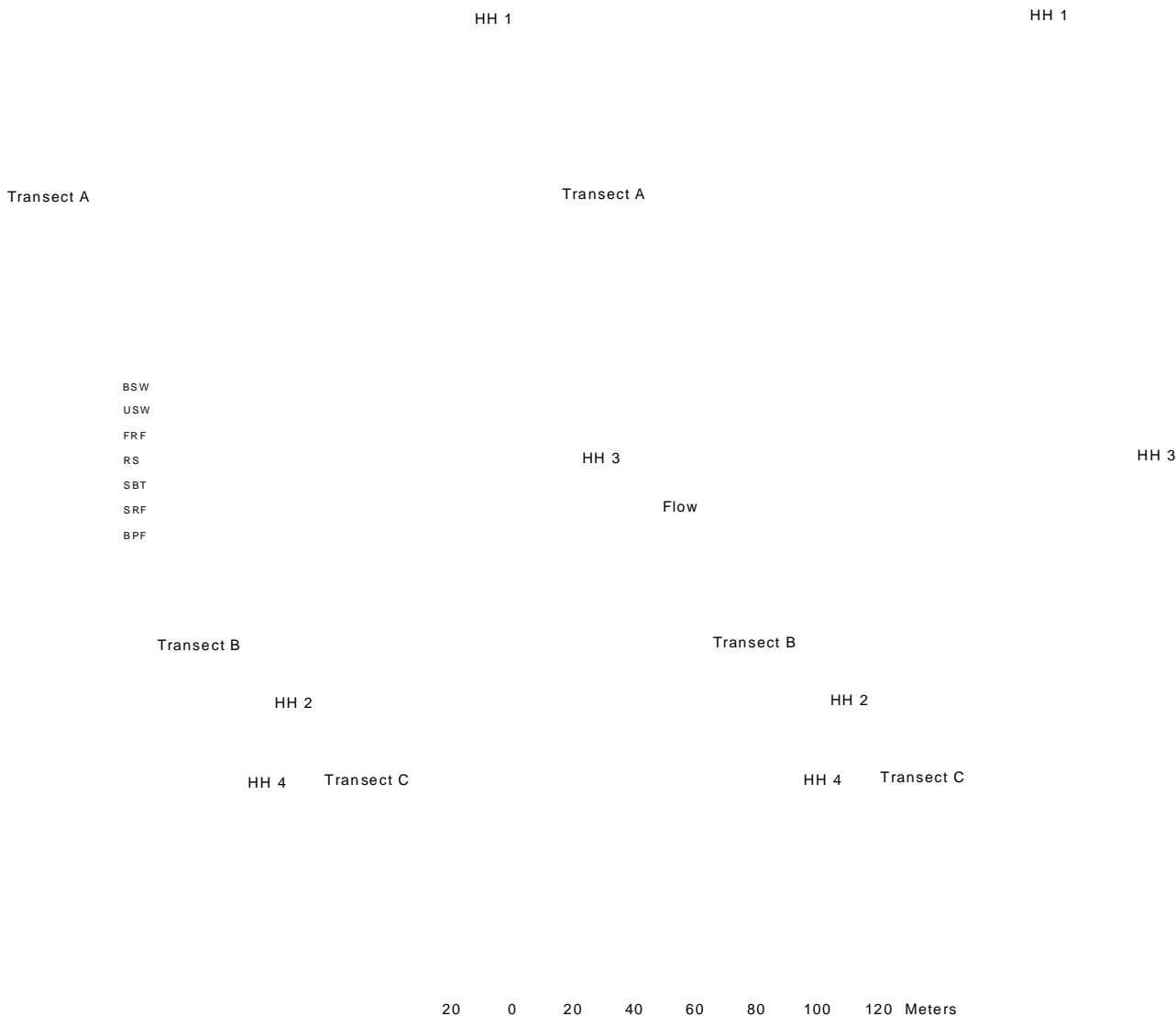


Figure 12.1 b) Flow type map for the Malibamatso River at Whitehills, IFR site 5, mapped at winter low flow. c) Flow type map for the Malibamatso River at Whitehills, IFR site 5, mapped at summer low flow.

Figure 12.2a Whitehills IFR 5. Hydraulic Habitat 1. \* = difference in vertical scale used.

Figure 12.2b Whitehills IFR 5. Hydraulic Habitat 2. Arrow = plus higher size classes that could not be measured.

Figure 12.2c Whitehills IFR 5. Hydraulic Habitat 3. Arrow = plus higher size classes that could not be measured.

Figure 12.2d Whitehills IFR 5. Hydraulic Habitat 4. Arrow = plus higher size classes that could not be measured. Too fast and too deep = could not be measured.

### 13 IFR SITE 6 - SEAKA BRIDGE

#### 13.1 General overview of the characteristics of IFR Site 6

The river is wide and relatively featureless, flowing smoothly through a wide valley. Though confined by banks some metres high, the landscape beyond that is one of gentle slopes. The area is rural, with widespread fields, roads and human habitation. Very large boulders or bedrock line the right bank of the site, together with a mix of trees. The left bank has a vertical, eroding earth bank, with isolated bushes and small trees at the foot of the bank. The top of the bank leads directly into cultivated fields. A road bridge crosses the river at the upstream end of the site with, immediately upstream of that, an old Department of Water Affairs rated section.

#### 13.2 Description of the physical-habitat component at IFR Site 6

Site visits were made in July 1998, September 1998 and January 1999. Mapping of channel form and substrata distribution was done by Skoroszewski at winter low flow

(July 1998) and added to by Tiale (Senqu Consultants) in August 1998. Flow maps were drawn by Skoroszewski at winter low flow (July 1998) and by King at summer low flow (January 1999). Hydraulic characterisation was done by Brown (September 1998) and King & Brown (January 1999).

#### 13.3 Results

The river bed at the site was almost entirely sand (Figure 13.1a). More than 99% of the wetted area was sand, with the remainder being one boulder and a small patch of gravel and mud (Table 13.1). The wetted width ranged from approximately 40 m to 160 m. The overall impression was of smooth, gliding flow: the only flow type present in summer was SBT, with this also being dominant in spring but with a slower strip of BPF along the edges (Figures 13.1b and 13.1c).

No characterisation of hydraulic habitats was done as the site was too deep.

Table 13.1 The area (m<sup>2</sup>) of wetted substrata covered by different flow types at IFR Site 6 (Seaka) in (a) September 1998 and (b) January 1999. See text for an explanation of acronyms for substratum and flow categories.

(a) IFR 6: September 1998

FLOW TYPE	B	S	TOTAL
BPF	0.00	5892.50	<b>5892.50</b>
SBT	40.09	30344.38	<b>30384.46</b>
<b>TOTAL</b>	<b>40.09</b>	<b>36236.88</b>	<b>36276.96</b>

(b) IFR 6: January 1999

FLOW TYPE	B	G	S	M	TOTAL
SBT	40.09	498.84	64136.07	53.45	<b>64728.44</b>
<b>TOTAL</b>	<b>40.09</b>	<b>498.84</b>	<b>64136.07</b>	<b>53.45</b>	<b>64728.44</b>

Seaka IFR site: 6  
Substrata  
8 January 1999

B  
G  
S  
M

Figure 13.1a Substratum map for the Senqu River at Seaka Bridge, IFR site 6, mapped at summer low flow.

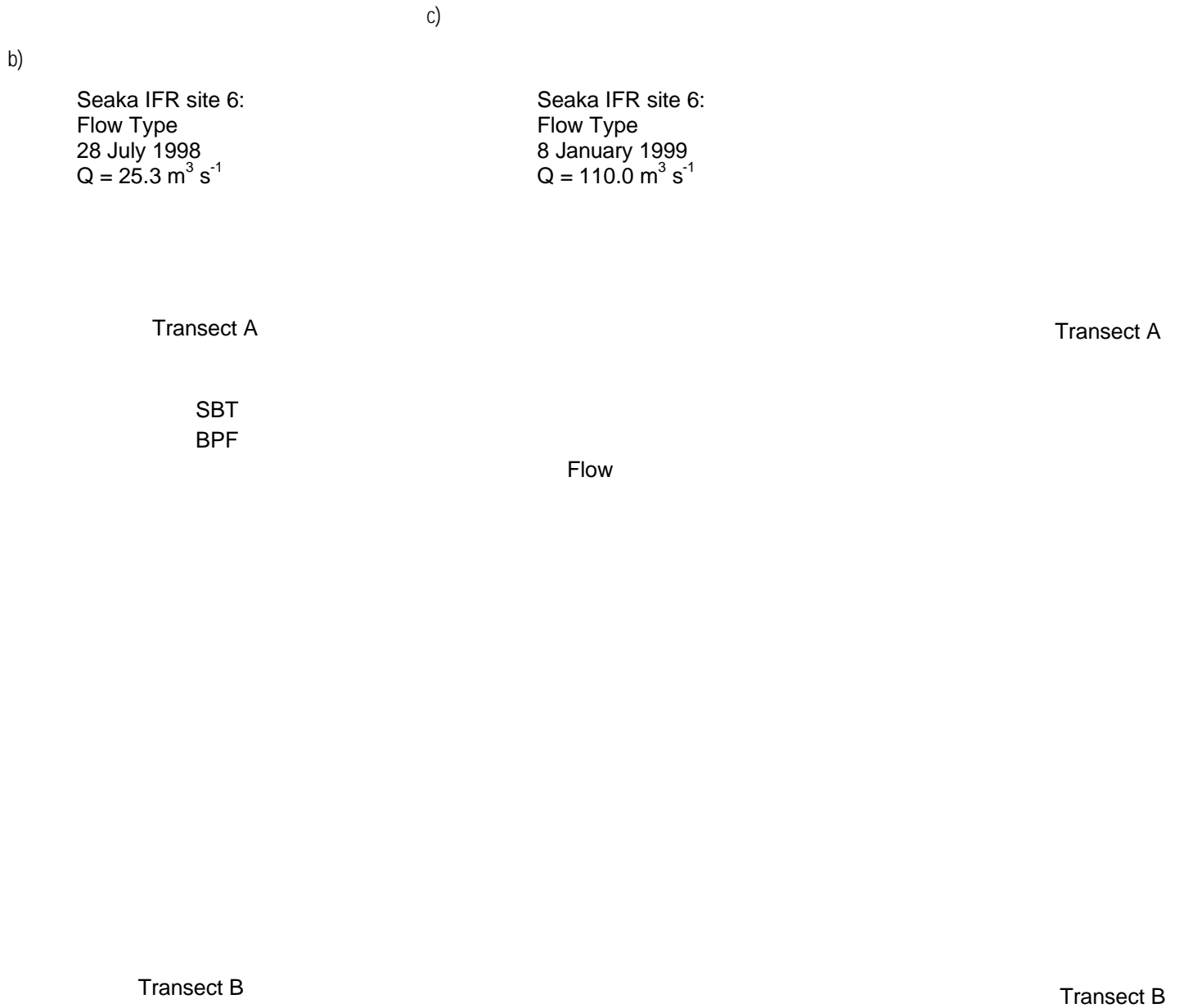


Figure 13.1 b) Flow type map for the Senqu River at Seaka Bridge, IFR site 6, mapped at winter low flow. c) Flow type map for the Senqu River at Seaka Bridge, IFR site 6, mapped at summer low flows.

## 14 IFR SITE 7 - MARAKABEI

### 14.1 General overview of the characteristics of IFR Site 7

The site is on the Senqunyane River, about 30 km downstream of the Mohale Dam construction site. It is located on a bend of the river, in a relatively flat-bottomed valley between steep mountain slopes. Like the Matsoku site, the river is contained on the bend by a cliff on the left bank and has a mid-channel island on the bend. The river is wide and smooth-flowing in the upper and lower thirds of the sites, but narrower with more turbulent flow around and immediately downstream of the island. Scattered trees line the right bank, with cultivated fields behind them. A footpath runs between the trees and the fields, which is used by people cultivating the fields and by fishermen who have been seen fishing at the site. The left-bank slopes are uncultivated near the river as they are rocky and steep, but fields occur higher up. The slopes are extensively grazed by domestic herds, which drink at the river.

### 14.2 Description of the physical-habitat component at IFR Site 7

Site visits were made in December 1997, June 1998, September 1998 and January 1999. Mapping of channel form and substrata distribution was initiated by King in December 1997 and completed by Skoroszewski at winter low flow (June 1998). Flow maps were drawn by King at winter low flow (June 1998) and summer low flow (January 1999). Hydraulic characterisation was done by King (June 1998), September 1998 (Brown) and King & Brown (January 1999). The September data were lost due to the political riots.

### 14.3 Results

The site was characterised by a boulder and a mixed boulder-cobble substratum (Figure 14.1a). There were also areas of bedrock, particularly on the outside of the bend and in the upstream end of the site. Small area of mixed cobble, with or without sand also occurred between the island and outside bank, and sand along the left side of the island. Overall, bedrock with or without overlying cobbles accounted for 31% of the wetted area, boulder and mixed boulder-cobble 63%, mixed cobble with or without sand 4% and sand 2% (Table 14.1). Single categories of substratum accounted for 43% of the wetted area. Outside of the central narrow area, the wetted width is about 40 m.

Upstream of the bend, the water flowed smoothly through a pool-like stretch, with the flow type SBT being predominate in both winter and summer (Figures 14.1b and 14.1c). The stretch downstream of the bend was also smoothly flowing, but flow changed from SBT in winter to incorporate a large central tongue of faster water (RS) in summer. The island was also surrounded by fairly quiet water in winter, with SBT and very shallow, slow flickering flow (SRF), but this changed to fast flow categories for about 40 m downstream. In summer, parts of the island were inundated, and flow around it became deeper and faster, with extended areas of BSW and USW and the introduction of cascades. Overall, 93 % of the wetted area had slow flow types in winter compared to 42% in summer.

Three hydraulic habitats were studied at the site (Figures 14.1b and 14.1c), and their hydraulic conditions measured on three occasions. One data set was lost, however, so data exist for winter (June 1998) and summer (January 1999). HH1 was in the two channels around the island. HH2 was downstream in the turbulent water, and HH3 was furthest downstream in the smoothly-flowing area.

The substratum at HH1 consisted of mostly larger categories, with high proportions of bedrock, boulders and large cobble (Figure 14.2a). Velocities were quite low in winter (up to 0.39 m s<sup>-1</sup>) and typified by SRF and SBT, but increased to a wide range (0.01-1.99 m s<sup>-1</sup>; BSW, USW and RS) in summer, reflecting the typical heterogeneous flow of fast water over large particles. Depths remained much the same in both seasons, up to 0.79 m. In winter, the rocks in the right channel were clean and non-slippery, whilst those in the left channel had a cover of photosynthesising algae. Downstream, the bedrock was covered with fine silt. Conditions were not recorded in summer.

HH2 was the boulder-bedrock rapid downstream of the island. Although smaller material lay over this area in winter (Figure 14.2b), much of this was swept away in summer leaving, at least at the edge which was the only area that could be measured, bare bedrock. Velocities typically covered a wide range from very low (in hydraulic cover) to > 2 m s<sup>-1</sup>. Although the whole area was sufficiently shallow for measurement in winter (up to 0.39 m), most of it was too deep (and fast-flowing) to be entered in summer. Flow categories were FRF, USW,

BSW and, in summer, cascades. In winter the rocks were clean (not recorded in summer).

HH3 was a downstream run, with smaller substrata including sand and mud (Figure 14.2c). One stepped down off the right bank into water about 0.50 m deep, and depth increased across the river so that by mid-stream it was always deeper than "wader depth". In some areas a

narrow strip along the right bank and under the trees had shallower water (0.10-0.50 m). Velocities were very low in winter (SBT and BPF: 0-0.09 m s<sup>-1</sup>), but in summer increased to 0.49 m s<sup>-1</sup> in the area that could be waded and perhaps higher further into midstream. In winter, patches of ice covered the water under the trees, and silt and algae were common on the boulders.

Table 14.1 The area (m<sup>2</sup>) of wetted substrata covered by different flow types at IFR Site 7 (Marakabei) in (a) June 1998 and (b) January 1999. See text for an explanation of acronyms for substratum and flow categories.

(a) IFR 7: June 1998

FLOW TYPE	BR	BR & LC & SC	B	B & LC & S	LC & SC	LC & SC & S	TOTAL
BPF	175.794	0.000	98.009	525.827	0.000	0.000	<b>799.630</b>
BSW	31.114	0.000	1.556	74.674	0.000	0.000	<b>107.344</b>
FRF	60.672	26.447	24.891	178.906	23.336	0.000	<b>314.252</b>
RS	48.227	0.000	0.000	101.121	0.000	0.000	<b>149.348</b>
SBT	2156.204	4.667	236.467	5578.749	60.672	171.127	<b>8207.886</b>
SRF	104.232	43.560	0.000	429.374	208.464	6.223	<b>791.853</b>
USW	107.343	0.000	0.000	46.671	0.000	0.000	<b>154.014</b>
<b>TOTAL</b>	<b>2683.586</b>	<b>74.674</b>	<b>360.923</b>	<b>6935.322</b>	<b>292.472</b>	<b>177.350</b>	<b>10524.327</b>

(b) IFR 7: January 1999

FLOW TYPE	BR	BR & LC & SC	B	B & LC & SC	LC & SC	LC & SC & S	S	TOTAL
BPF	40.644	0.000	94.836	389.881	0.000	0.000	0.000	<b>525.361</b>
BSW	337.195	28.601	0.000	340.205	19.569	9.032	78.277	<b>812.879</b>
CASCADES	174.619	0.000	1.505	33.117	0.000	0.000	0.000	<b>209.241</b>
FRF	0.000	0.000	156.555	331.173	0.000	0.000	1.505	<b>489.233</b>
RS	993.520	7.527	593.101	2744.221	129.459	132.469	126.448	<b>4726.745</b>
SBT	1797.367	0.000	296.551	2352.835	0.000	0.000	0.000	<b>4446.753</b>
SRF	0.000	0.000	1.505	69.245	0.000	0.000	0.000	<b>70.750</b>
USW	459.126	39.139	136.985	439.557	144.512	39.139	73.761	<b>1332.219</b>
<b>TOTAL</b>	<b>3802.471</b>	<b>75.267</b>	<b>1281.038</b>	<b>6700.234</b>	<b>293.540</b>	<b>180.640</b>	<b>279.991</b>	<b>12613.181</b>

Marakabei IFR Site 7  
Substrata  
8 January 1999

Figure 14.1a Substrate map for the Senqunyane River at Marakabei, IFR site 7, mapped at summer low flow.

b)

c)

Marakabei IFR site 7:  
Flow Type  
9 June 1998  
Q = 0.78 m<sup>3</sup> s<sup>-1</sup>

Marakabei IFR site 7:  
Flow Type  
8 January 1999  
Q = 16.9 m<sup>3</sup> s<sup>-1</sup>

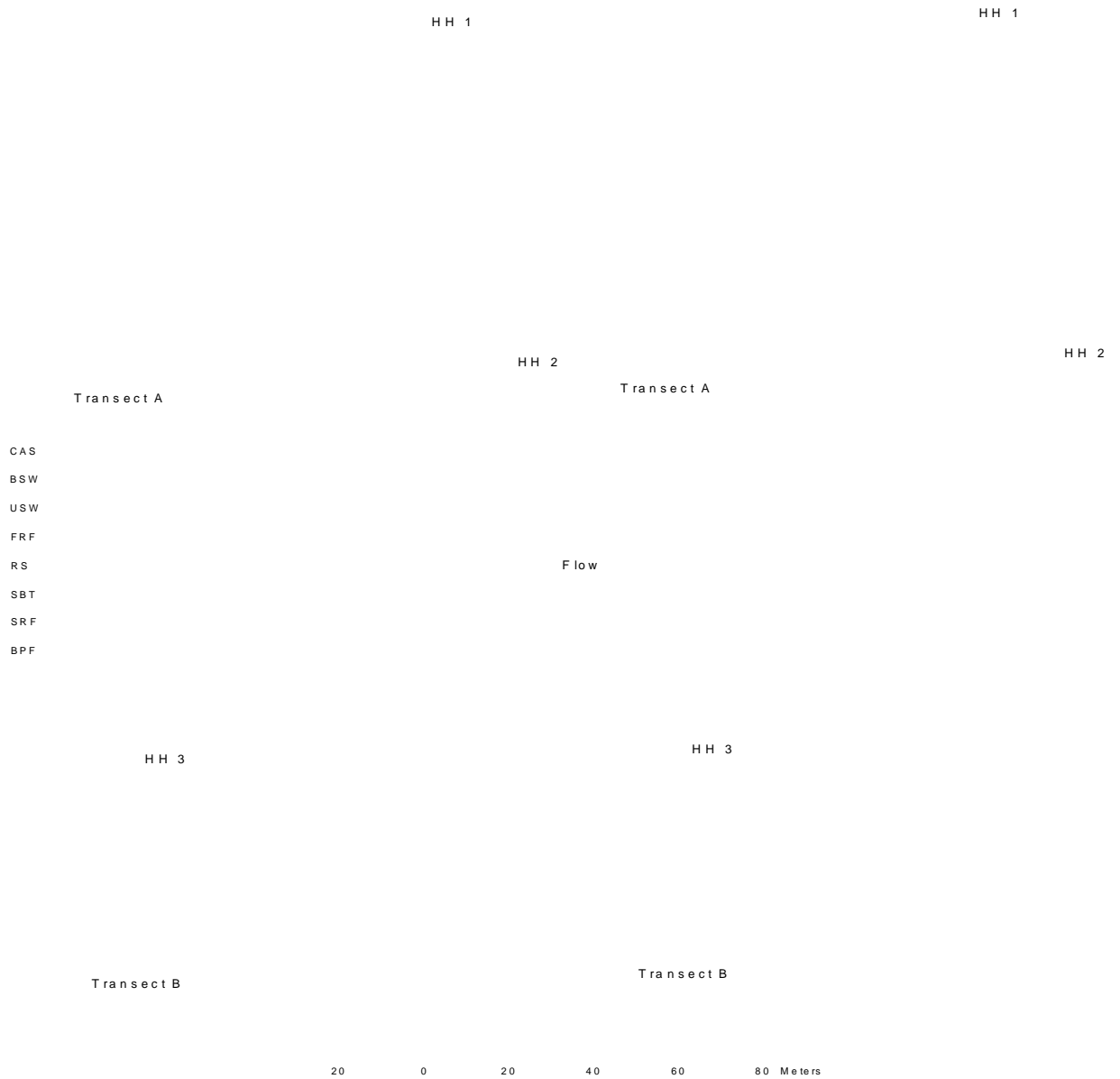


Figure 14.1 b) Flow type map of the Senqunyane River at Marakabei, IFR site 7, mapped at winter low flow. c) Flow type map of the Senqunyane River at Marakabei, IFR site 7, mapped at summer low flow.

Figure 14.2a Marakabei IFR. Hydraulic Habitat 1.

Figure 14.2b Marakabei IFR. Hydraulic Habitat 2.

Figure 14.2c Marakabei IFR. Hydraulic Habitat 3.

**15 IFR SITE 8 – LOWER SENQUNYANE**

**15.1 General overview of the characteristics of IFR Site 8**

The site is on the Senqunyane River, just upstream of its confluence with the Senqu. It is located in a flat-bottomed valley, with steep mountain slopes on both sides. There are no roads or footpaths at the site. Earth banks covered with grass slope gently down to the river in some places, whilst at the upstream end of the site the river swings to the left where a steep cliff confines the right bank of the channel. Domestic herds graze on the slopes and are watered at the river.

**15.2 Description of the physical-habitat component at IFR Site 8**

Site visits were made in July 1998, September 1998 and January 1999. Mapping of channel form and substrata distribution was done by Skoroszewski at winter low flow (July 1998). Flow maps were drawn by Skoroszewski at winter low flow (July 1998) and by King at summer low flow (January 1999). Hydraulic characterisation was done by Brown (September 1998) and King & Brown (January 1999). In summer, the site had to be visited by helicopter, due to weather conditions and problems of accessibility.

**15.3 Results**

The main substrata at the site were sand and mixed sand and gravel (Figure 15.1a). There were some areas of boulder and mixed boulder and sand, but these are out of the water on the inside of the bend in what is presumably a flood channel. Overall, mixed sand and gravel

accounted for 99% of the wetted area in winter and for 52% in summer when flows expanded over sandy edge areas (Table 15.1). The remaining proportions were unmixed sand.

Flow types were dominated by SBT in winter (86%) (Figure 15.1b) and by RS in summer (67%) (Figure 15.1c). A small area of faster water was present over gravel/sand at the downstream end of the site. The wetted width was 30-80 m at different places and times of the year.

Two hydraulic habitats were selected, each described by a single cross-channel transect. HH1 was at the upstream end of the site, by the cliff, and HH2 at the downstream end, partially incorporating the area of faster flow.

HH1 had bedrock intrusions near the shoreline, from the cliff face, changing to a sand and gravel substratum instream (Figure 15.2a). Velocities were quite fast for the SBT flow-type, reflecting the depth of the water and the small particle size of the substrata. In spring, depths ranged to 0.49 m, but in summer were > 0.99 m. At that time, velocities could not be measured because of the depth.

HH2 was measured in spring, but the data were lost. Water velocities and depths were high, ranging beyond what could be measured (Figure 15.2b). The flow types RS and USW in such deep water made entry into the water impossible.

Table 15.1 The area (m<sup>2</sup>) of wetted substrata covered by different flow types at IFR Site 8 (Senqunyane) in (a) September 1998 and (b) January 1999. See text for an explanation of acronyms for substratum and flow categories.

(a) IFR 8: September 1998

FLOW TYPE	G & S	S	TOTAL
BPF	730.13	107.21	<b>837.34</b>
RS	220.89	0.00	<b>220.89</b>
SBT	6475.99	0.00	<b>6475.99</b>
USW	34.20	0.00	<b>34.20</b>
<b>TOTAL</b>	<b>7461.20</b>	<b>107.21</b>	<b>7568.41</b>

(b) IFR 8: January 1999

FLOW TYPE	G & S	S	TOTAL
RS	5379.87	4412.21	<b>9792.08</b>
SBT	1828.10	2558.23	<b>4386.33</b>
USW	468.58	0.00	<b>468.58</b>
<b>TOTAL</b>	<b>7676.55</b>	<b>6970.44</b>	<b>14646.99</b>

Lower Senqunyane  
IFR Site 8:Substrata  
7 January 1999

Figure 15.1a Sustratum map for the Senqunyane River at the Senqu confluence, IFR site 8, mapped at summer low flow.

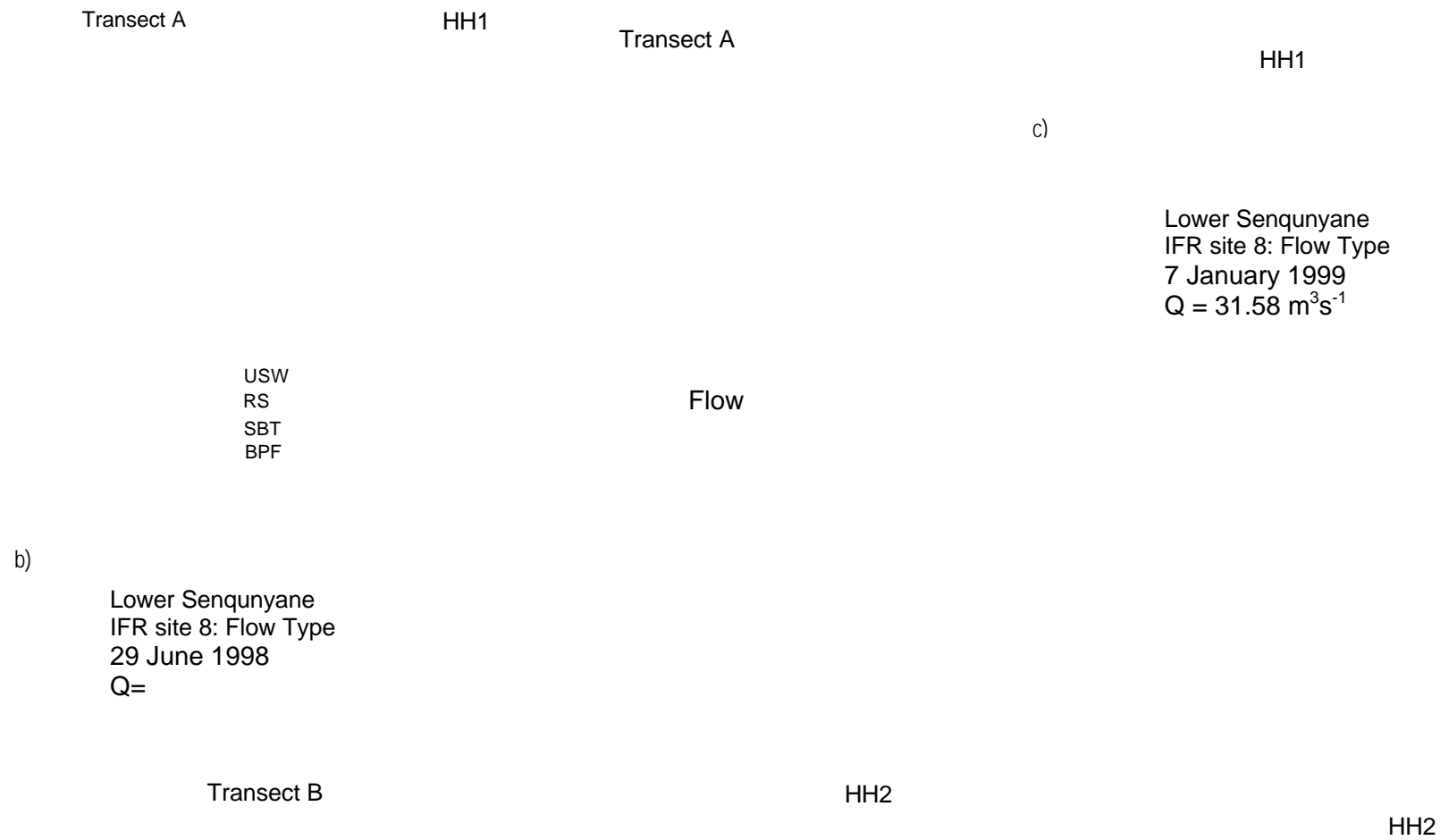


Figure 15.1 b) Flow type map for the Senqunyane River at the Senqu confluence, IFR site 8, mapped at winter low flow. c) Flow type map for the Senqunyane River at the Senqu confluence, IFR site 8, mapped at summer low flow.

Figure 15.2a Lower Senqunyane IFR 8. Hydraulic Habitat 1. Arrow = plus higher size classes that could not be measured.

Figure 15.2b Lower Senqunyane IFR 8. Hydraulic Habitat 2. Arrow = plus higher size classes that could not be measured.

**16 SUMMARY OF THE PRESENT-DAY PHYSICAL-HABITATS OF THE LESOTHO RIVERS RELATIVE TO THEIR NATURAL CONDITION**

This cannot be assessed as no previous data of this kind exist for the rivers.

## PART 6: FLOW-RELATED INFORMATION

### 17 FLOW RELATED INFORMATION

The habitat maps and flow types described in this report are the subject of ongoing research. Eventually, it is hoped to be able to describe how flow-type proportions change with discharge and use this to calibrate a model (still to be created) that will simulate conditions, or at least proportions of different flow types, at un-mapped discharges. Additionally, research is underway to establish the link between flow types and recognised hydraulic indices such as Froude numbers. Once such relationships become more clear, it may be possible to introduce aquatic scientists to the gentle "art" of hydraulics in a form that is more intuitively understandable. But that lies in the future, and will not be available for this project, where the most that is possible is to describe conditions during a

summer and a winter low-flow period. To put these two sets of data into context of their representativeness of prevailing conditions, the discharges occurring on those two occasions may be assessed in terms of their percentiles on annual, monthly and seasonal low-flow duration curves (FDCs). These FDCs will be available at the IFR Workshop.

In their present form, then, the maps and accompanying statistics cannot be incorporated into a working model to predict how conditions change with discharge, because such a model does not exist. However, they stand as a record of conditions at the IFR sites that can be used to assess future flow-related changes.



**PART 7: BIO-PHYSICAL FUNCTIONS OF DIFFERENT ASPECTS OF THE FLOW  
REGIME****18 ASPECTS OF THE NATURAL FLOW REGIME THAT SHOULD BE MAINTAINED TO ADEQUATELY PROTECT PARTICULAR FEATURES OF PHYSICAL HABITAT****18.1 Low flows**

The main concern regarding maintenance of physical habitat at low flows is simply one of maintaining wetted habitat. Whilst less wetted habitat than usual may mean a change in flow types and water quality, it almost certainly means less habitat for aquatic biota. Some shrinkage of habitat is inevitable during the dry season. For instance, Hollands (in press) showed that shrinkage of wetted perimeter past the point where banks were becoming exposed to the point where the bed was becoming exposed, was a natural feature of Western Cape (South Africa) headwater streams. Tharme (in press) experimentally diverted different proportions of the total discharge of some of these same streams and recorded the consequences in terms of the availability of different wetted habitats and responses of the aquatic invertebrates. She concluded, *inter alia*, that the *proportions* of different habitats change from normal at such times, and that though the fauna appear to some extent to be able to cope with this in the short term by moving into unfavourable habitat, the long-term implications remain unknown. Kleynhans (South African Department of Water Affairs and Forestry, pers. comm.) found much the same for riffle-dwelling fish of rivers in the Limpopo basin. They moved into pool-like stretches as riffles dried out during a severe drought, but were missing from the river in follow-up surveys some months after flows strengthened again. Hence, from the perspective of instream biotas, low flows may be seen as an exceedingly important component of the total flow regime.

**18.2 High flows**

The UCT research on habitat mapping (King & Schael, in prep.) has highlighted the patterns of distribution of

substrata of different sizes. One of the findings from this mapping is that some rivers have well-sorted substrata, with particles of any one size well delineated in different parts of the site. Physical heterogeneity at the microhabitat level may be seen as high at these sites. Other rivers have more poorly sorted substrata; their physical heterogeneity thus appears to be lower. Some of the poorly-sorted rivers were simply "middle rivers": some way along the longitudinal profile and thus predictably having a bed of rocks embedded to some extent in sand. Other poorly-sorted rivers, however, were headwaters that were suffering from some anthropogenic disturbance. A tentative conclusion, based on very sparse data, was that dams might be reducing sorting, and thus physical heterogeneity, of downstream stretches, due to the loss of floods. Geomorphologists point out that all flows "work" the river bed to a greater or lesser extent, and dams may reduce this to the point where much of the bed is covered by much the same mix of substrata.

The results of this contract show that this reduction is not happening yet at the Katse site, IFR Site 2. There are considerable amounts of silt and algae at the site, but the underlying sorting of larger particles remains high. It is not known how long a loss of sorting might take.

**18.3 and 18.4 Natural flow variations and patterns**

Addressed under 18.1 and 18.2.



**PART 8: ACKNOWLEDGEMENTS AND REFERENCES****19 ACKNOWLEDGEMENTS**

Following requests from the biophysical team, additional funding was made available by the Client to allow habitat maps to be drawn of all eight sites, rather than of the three super-sites as originally planned. This has allowed a far better understanding of the sites, and is felt to be a valuable additional component of the study. The maps could not have been completed without the help of members of Senqu Consultants, particularly Rob Skoroszewski, who are warmly thanked for their input. Drew Birkhead and Martin Thoms (biophysical team), Lekhetho Lesenyeho (surveyor) and Roz Townsend (Southern Waters) also helped with aspects of the mapping exercises. Southern GIS, Cape Town, efficiently digitised the maps to our specifications, and Justine Fowler of Southern Waters is particularly thanked for her patient work in converting these data to the final coloured maps with accompanying tables. Mr Bruce Paxton of the Zoology Department, University of Cape Town, assisted with map preparation, and produced the frequency plots. The mapping exercise emanated from research within a project titled Linking Abiotic and Biotic Data on South African Rivers being done by Dr King and Ms D. Schael and funded by the South African Water Research Commission.

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