A REVIEW OF THE FLUVIAL GEOMORPHOLOGY MONITORING OF THE RECEIVING STREAMS OF THE MOOI-MGENI RIVER TRANSFER SCHEME PHASE 1

By
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ABSTRACT

The Mgeni River is the major water resource for the eThekwini Metropolitan and Msunduzi Municipalities. At the end of 2002, the Mooi-Mgeni Transfer Scheme Phase 1, which transfers water from the Mooi River into the Mgeni catchment to augment the water supply to this region, was completed. The interbasin transfer of water resulted in the loss of habitat, erosion of the stream channel and transformation of the riparian zone in the receiving streams. Stream regulation resulting in an altered flow regime is considered the greatest threat to a riverine environment. An Environmental Management Plan (EMP), incorporating fluvial geomorphological monitoring procedures, was implemented to monitor the impact of the transfer on the receiving streams, the Mpofana and Lions Rivers, and to determine the rate and magnitude of erosion.

A comparison of the geomorphological monitoring procedure of the EMP with best practice geomorphological monitoring derived from a review of the national and international stream geomorphological literature was conducted in this study. In addition, the implementation of the EMP geomorphological monitoring procedures was described and onsite observations of physical impacts on the receiving streams were completed. The geomorphological monitoring of the EMP included the use of erosion pins, survey of stream cross-sections and fixed-point photography. Photographs and data were collected from February 2003 to June 2006.

The comparison of these monitoring methods against stream assessment best practices revealed the strengths and weaknesses of the geomorphological monitoring implemented in the receiving streams. Several key weaknesses were revealed. Firstly, an inadequate number of stream cross sections was included in the monitoring procedures. Secondly, although the erosion pins indicated some general trends in the erosion of the stream channel, they did not give a true impression of the rate and magnitude of change in slope and channel width of the stream, and the location of the erosion pins sites did not take into account the actual direction of flow during transfer as erosion pin sites were selected during low flow conditions. In addition, it was difficult to determine whether the erosion pins had been lost due to erosion or to turbulence. The results were difficult to assess and did not show whether the erosion was localised at the pins or the section of bank or stream profile. Thirdly, analysis of platform changes in the stream channel (e.g. through a comparison of aerial photograph sets) was lacking and no attempt was made to integrate the results from the different methods.

Overall, the study concluded that the geomorphological monitoring of the EMP was limited, and it did not highlight the rate and magnitude of erosion in the receiving streams. Based on the findings of this study, recommendations are provided for geomorphological monitoring of the receiving streams of the Mooi Mgeni Transfer Scheme.

DECLARATION

I Alistair Malcolm Scott Hunter declare that

- (i) The research reported in this dissertation, except where otherwise indicated, is my original work.
- (ii) This dissertation has not been submitted for any degree or examination at any other university.
- (iii) This dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other researchers.
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Signed: ______________________________ Date: ____________

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LIST OF ABBREVIATIONS AND ACRONYMS USED

aMSL	above Mean Sea Level
ASPT	Average Score per Taxon
AUSRIVAS	Australian River Assessment System
BBM	Building Block Method
BKS	BKS Consulting Engineers
CAD	Computer Aided Design
CARA	Conservation of Agricultural Resources Act No 43 of 1983 (South Africa)
CMA	Catchment Management Agency
CMF	Catchment Management Forum
DAEA	Department of Agriculture and Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DWAF	Department of Water Affairs and Forestry
ECA	Environmental Conservation Act No 73 of 1989 (South Africa)
ECS	Evaluation Corridor Section (UK)
EIA	Environmental Impact Assessment
EIR	Environmental Impact Report
EMAP	Environmental Monitoring and Assessment Programme (US EPA)
EMAP WSA	Wadeable Streams Assessment
EMP	Environmental Management Plan
EMS	Environmental Management Strategy
EPSRC	Engineering and Physical Science Research Council
EWG	Environmental Working Group
FDMS	Flood Defence Management System (United Kingdom)
FISRWG	Federal Interagency Stream Restoration Working Group
FSL	Full Supply Level (Dam 100% full)
GPS	Global Positioning System
GIS	Geographical Information Systems
IBT	Interbasin Transfers
IEM	Integrated Environmental Management
IFR	In-stream Flow Requirements

IHAS	Integrated Habitat Assessment System
IWR-E	Institute for Water Research-Environmental
IWR	Institute for Water Research
KZN	KwaZulu-Natal
MMTS-1	Mooi-Mgeni Transfer Scheme, Phase 1
MSAT	Mgeni Systems Allocation Tool
NAEBP	National Aquatic Ecosystem Biomonitoring Programme
NEMA	National Environmental Management Act No 107 of 1998 (South Africa)
NRHP	National River Health Programme (Australia)
NWA	National Water Act, No 36 of 1998 (South Africa)
RCT	River Community Types
RDM	Resources Directed Measures
RHP	River Health Programme (South Africa)
RoD	Record of Decision
RHS	River Habits Survey (British)
RRMF	Receiving Rivers Management Forum
SASS 5	South African Scoring System 5 (Biological Scoring System)
SRK	Stefan Robertson and Kirsten Engineering and Environmental Consultants
TOR	Terms of Reference
USDA	United States Department of Agricultural Forestry Services
US EPA	United States Environmental Protection Agency
USGS	United States Geological Services
UW	Umgeni Water
WfW	Working for Water (South African Alien Invasive Plant Eradication Programme)

GLOSSARY OF TERMS

Fluvial Geomorphology, the study of the features, shapes and forms that are formed by running water and river systems (Freeman and Rowntree, 2005).

Meander, a circuitous winding or bend in river or stream (Parlone and Todd, 1997).

Receiving stream, the stream or river that water is released or discharged into from a pipeline or canal.

Riffle is a term used in describing a section of a stream where the water flows over coarse gravel and the waves look as though they are motionless (Freeman and Rowntree, 2005).

Stream system, also known as a fluvial system, is a fundamental unit of study for fluvial processes that consists of a network of stream channels and tributaries (Ritter, 2006).

Stream environment, the term used to describe the constituents of a stream, i.e. the vegetation, rocks, soil, pebbles and water.

Stream Thalweg, the term used for the line of lowest connected points in a stream channel cross-section or the line of fastest flow along a river's course (Soanes and Stevenson, 2005).

Wadeable stream is a stream that is shallow enough to be waded without endangering human life or perennial streams in which samples and measurements can be taken without the use of a boat.

1. INTRODUCTION

1.1 Background

With rapid population growth, rising urbanisation, an expanding economy, and improved water supply services within the KwaZulu-Natal metropolitan areas, water requirements are expected to exceed supply (Mullins *et al*., 2007). The present water demand for eThekwini Municipality is 363 million m^3/annum and it is forecast that the water demand will grow to approximately 656 million m^3/annum after 2027 (Umgeni Water, 2007).

In 1983, during a drought that affected water supply to the eThekwini Metropolitan Municipality and the Msunduzi Municipality, the Department of Water Affairs and Forestry (DWAF) constructed the Mearns Emergency Transfer Scheme. The Mearns Emergency Transfer Scheme enabled the transfer of raw water from the Mooi River into the Mgeni catchment. The scheme consisted of a 3m high weir, a pump station on the Mooi River (a tributary of the uThukela River), and a steel pipeline. The steel pipeline is divided into two sections: the first section is 1.4m in diameter and 13.3km in length, and the second then divides into two 0.9m diameter steel gravity pipes, 8.3km in length (Umgeni Water, 1996). The pipeline outfall is located on the Mpofana stream close to Balgowan (Figure 1.1). The Mpofana stream is a tributary of the Mgeni River, upstream of Midmar Dam. The scheme was limited due to the following:

1. The supply of water from the donor system was limited by the volume impounded, and

2. A maximum of 1.6 m^3/s could be transferred, as greater flow rates inundated sections of stream banks, thus limiting access by landowners (Henderson, 1995: a).

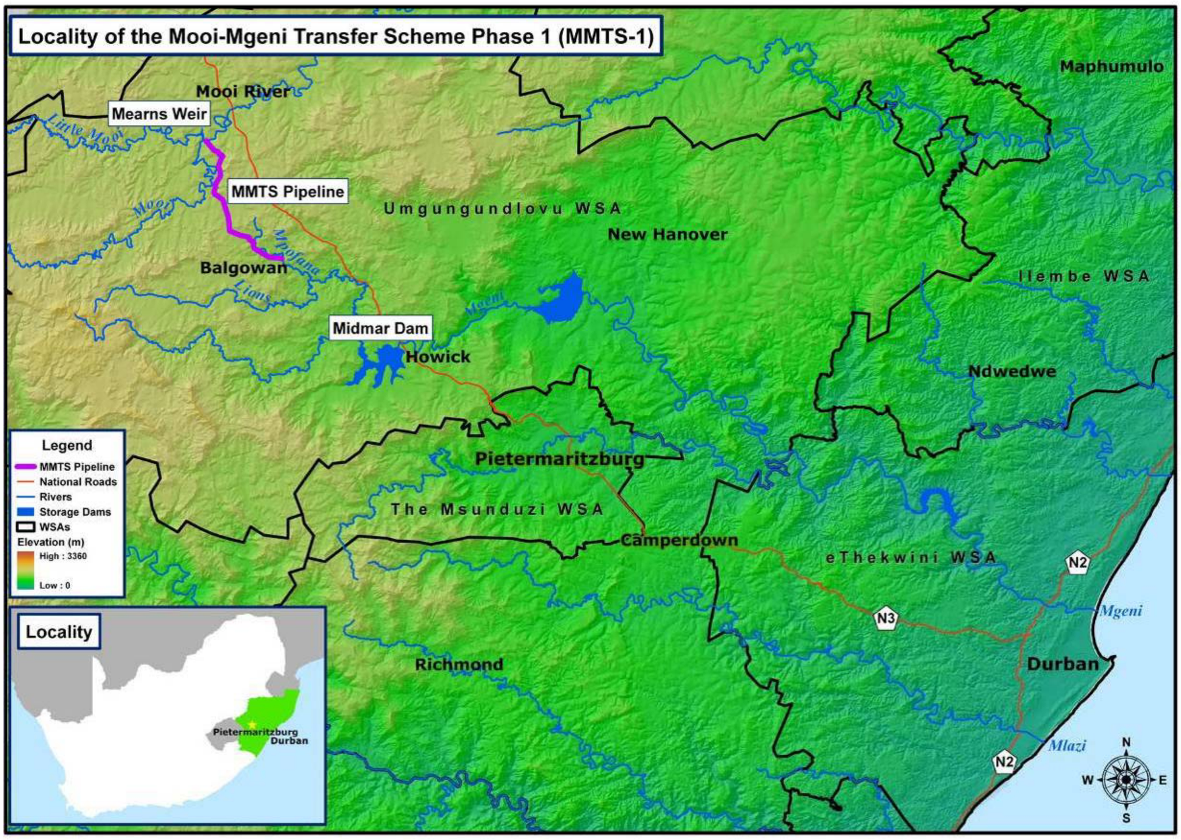


Figure 1.1 Locality of the Mooi-Mgeni Transfer Scheme (Umgeni Water, Engineering and Scientific Services Section).

During 1994, the Mgeni River system was the subject of a water supply study undertaken by consulting engineers, BKS, who provided water resource development plans aimed at ensuring water supply to the eThekwini Metropolitan and Msunduzi Municipalities until 2025 (Umgeni Water, 1996). This study concluded that the most feasible option to augmenting the water supply and increase security of supply to Midmar Dam was the upgrading of the Mearns Emergency Transfer Scheme. The upgrade consisted of the construction of a dam at the existing Mooi River weir site, utilising the existing pumps and pipeline infrastructure and the purchasing by DWAF, of the servitude along the receiving streams, which would allow the increased volume from the donor supply (Huggins, *et al*., 2002). The Mearns Emergency Transfer Scheme upgrade became known as the Mooi-Mgeni Interbasin Transfer Scheme Phase 1 (MMTS-1).

In the planning for the upgrade, DWAF and Umgeni Water commissioned several studies to consider the impacts of the proposed upgrade of MMTS-1 on the geomorphology of the receiving streams. These are discussed in more detail in Section 3.3. The studies made recommendations, which were incorporated into the Environmental Management Plan (EMP) as per requirements of the Environmental Conservation Act (ECA) (73 of 1989). This EMP formed the framework for the implementation of a monitoring programme to monitor change in the geomorphology of the receiving streams.

The Mpofana stream is a relatively small stream that drains predominantly through extensive agricultural land, and is considered a minor tributary in the Mgeni River catchment. The total natural length of the receiving stream is 39.9 km (Huggins, *et al*., 2002), which includes the Lions River reach, which feeds into the Mgeni upstream of Midmar dam (Figure 1.1).

1.2 Role of Umgeni Water in the Management of the Mooi-Mgeni Interbasin Transfer Phase 1 (MMTS-1)

Umgeni Water (UW) is a Water Services Provider, based in Pietermaritzburg, KwaZulu-Natal, South Africa. Umgeni Water's core business is resource monitoring, abstraction, treatment and bulk distribution of water, delivering in excess of 370 000 Mega litres per year to an area of over 24 000 km^2 that includes Durban and Pietermaritzburg (Umgeni Water, 2007). Umgeni Water owns and manages ten storage supply dams, thirteen water-works and three wastewater works.

DWAF developed the MMTS-1 scheme to augment supply to Midmar Dam. This scheme included the raising of the dam wall, which was completed at the beginning of 2003. In accordance with the Draft DWAF/Umgeni Water Operations Agreement for the management of bulk water supply to the Pietermaritzburg–Durban area, Umgeni Water has been given the responsibility to undertake the management of infrastructure and environmental monitoring of the MMTS-1. The contents of the Draft DWAF/Umgeni Water agreement have been under discussion with DWAF for many years and, at the time of this MMTS-1 geomorphological monitoring review (June 2009), there was no signed management agreement between the implementing agency, DWAF and the management agency, Umgeni Water. There is only a verbal agreement between both parties. The consequences are a lack of clarity on the roles and responsibilities of each agency. Umgeni Water is responsible for the fluvial geomorphological monitoring, but not the implementation of rehabilitative measures to sites, which have been impacted by the transfer. The rehabilitation of the receiving streams remains the responsibility of the DWAF.

The environmental monitoring for the MMTS-1 receiving streams, which includes fluvial geomorphological monitoring, forms the basis of this review. This review relies on the availability of fluvial geomorphological monitoring data, fixed-point photographs and onsite observations. Additional information was deemed necessary to provide a yardstick against which the geomorphological monitoring procedures and data collected could be assessed.

1.3 Background to the Research

In November 2002, Umgeni Water, prior to the completion of the MMTS-1, implemented fluvial geomorphological monitoring, with the setting of erosion pins and surveying stream cross-sections at the monitoring sites in accordance with the EMP. After the initial transfer ending 2003, the author was designated to collect the fluvial geomorphological monitoring data, which consisted of erosion data, fixed-point photography and on site observations. The author undertook subsequent fluvial monitoring data surveys between transfers. The survey data from these sites form the basis on which management decisions are to be made on whether remedial measures are required to limit erosion. This review sets out to establish the appropriateness of the geomorphological monitoring in determining the impact of the interbasin transfer on the receiving streams. While the institutional arrangements for management of the MMTS-1 have a critical influence over the sustained implementation of the monitoring and over how the results of the monitoring are translated into management and remedial actions, these institutional arrangements were beyond the scope of this review.

1.4 Study Aims and Objectives

The aim of this study is to determine whether the geomorphological monitoring procedures and data collated from the MMTS-1 receiving streams were appropriate and effectively implemented to monitor stream erosion of an interbasin transfer.

This aim encompassed the following objectives:

1. To review the literature on international and national norms and standards used for stream geomorphology assessments;

2. To describe the geomorphology monitoring procedures implemented to monitor the impacts of the transfer on the geomorphology of the MMTS-1 receiving streams;

3. To consider the appropriateness of the monitoring procedures for the MMTS-1 receiving streams by comparing them against national norms and standards, and to assess how effectively the procedures were implemented, and

4. To recommend ways to improve the geomorphological monitoring procedures prior to the implementation of Phase 2 of the MMTS.

2. LITERATURE REVIEW

Given the complex relationship between stream flow regimes, channel morphology and riparian habitat, this literature review aimed to:

1. Outline some key concepts of determining the geomorphological change of a stream;

2. Review the international and national fluvial geomorphological assessment procedures used to determine change, and

3. Identify norms and standards for assessing the geomorphological change of streams based on the fluvial geomorphological assessment procedures that were reviewed.

2.1 Some Key Geomorphological Concepts for Assessing Change

In the hydrological system, water weathers, transports and deposits sediments, shaping the landscape (Perry and Vanderklien, 1996, Skinner and Porter, 2000 and Ellery *et al*, 2008). In this system, rainfall characteristics such as intensity and duration patterns and the surface on which the rain falls (i.e. soils, rock type and vegetation cover) influence runoff (Davies and Day, 1998 and Ellery *et al*, 2008). Streams are the result of runoff which erodes the soils and transports sediment, which in turn shape the landscape and form the characteristics of a stream (Perry and Vanderklien, 1996; Davies and Day, 1998; Ellery *et al*, 2008). Processes within streams function as an integrated complex system of a number of variables, of which discharge rate, velocity, slope, channel shape and sediment load are interrelated. This relationship tends to adjust slope and channel morphology to accommodate the volume of water discharged, and sediment load transported (Harrelson *et al*. 1994; Rosgen, 1994 and Ellery *et al.* 2008). Ellery *et al.,* (2008: 35) comments that the *"characteristics of rivers are shaped by their interaction with rocks and sediment"*. Bedrock streams are characterised by the transportation of bed-load material having a relatively steep slope and a discharge that is generally irregular in nature. Alluvial streams are characterised by having suspended material that is dominant, a discharge that is generally regular, and a gentle gradient (Harrelson *et al.,* 1994; Rosgen, 1994 and Ellery *et al.,* 2008). Erosion of the bank occurs on the outside of bends, and deposition on the inside (Rosgen, 1994 and Ellery *et al.,* 2008).

Deposition and erosion are therefore naturally occurring processes, as the stream tends to erode to what is commonly referred to as, base level (Ellery *et al*., 2008). The base level is considered to be the lowest level to which a stream may erode, be it sea level or at the confluence of two rivers or an impoundment (Ellery *et al*., 2008). The composition of the streambed therefore indicates whether erosion or deposition is occurring within the stream, but not the rate or magnitude of erosion or deposition (Harrelson *et al.,* 1994; Perry and Vanderklien, 1996; Rosgen, 1994; Ellery *et al.,* 2008).

2.1.1 Stream Stability

Hydrologists describe a stream's state as being in "equilibrium" or in a stable state when erosion and deposition are occurring equally. Rosgen (1996 in Rosgen 2001 b, 2) defines stream channel stability as *"the ability of a stream, over time, in the present climate, to transport the sediment and flow produced by its watershed in such a manner that it maintains its dimension, pattern and profile".* Ellery *et al*, (2008, 37) indicate *"a river is in equilibrium if its channel form and gradient are approximately balanced to transport the supplied water and sediment available so neither deposition nor erosion occurs".* The process of erosion and deposition occurs in a natural stable channel but, if either erosion (degradation) or deposition (aggradation) increases, the stream is said to be unstable (Rosgen, 2001 b). The instability in the stream channel is therefore indicated by the increase in sediment supply to the downstream reach, deterioration of riparian habitat and land, and changes in channel evolution with the loss of physical and biological function (Rosgen, 2001 b).

To assist in understanding of aggradation and degradation, the following definitions are highlighted:

1. *"Aggradation is the process by which a stream's gradient steepens due to increased deposition of sediment (or a decrease in stream discharge)*, and

2. *Degradation is the process by which a stream's gradient becomes less steep, due to the erosion of sediment from the streambed. Such erosion generally follows a sharp reduction of the amount of sediment entering the stream (or an increase in stream discharge)"* (Endreny, 2006: 3).

The characterisation of a stream's state therefore allows the hydrologist to identify the "state of the stream", and to determine reference reaches and compare stream types.

Stream flow, which is the volume of water passing a given point per unit time, is described as the discharge rate (Harrelson *et al.,* 1994). The discharge rate is considered to have the greatest influence on the geomorphology of the stream (Harrelson *et al.,* 1994; Rosgen, 1994; Perry and Vanderklien, 1996; and Rosgen, 2001 b). The change or increase in the discharge rate within a stream alters the flow regime, which in turn influences the erosion and deposition rate increasing sediment movement.

2.1.2 Bankfull and Active Floodplain

Bankfull, also commonly termed dominant discharge (Rowntree and du Plessis, 2003), is defined as a point at which the stream channel is about to flood the active floodplain (Figure 2.1). At this point, the stream is effectively transporting the largest amount of sediments. Freeman and Rowntree (2005: 19) comment, *"Bankfull discharge is thought to control the form of an alluvial channel"* and Harrelson *et al*., (1994: 33) comments *"Erosion, sediment transport and bar building by deposition are most active at discharges near bankfull"*. Once flooding of the active floodplain occurs, the stream energy is spread over a greater area (Figure 2.1).

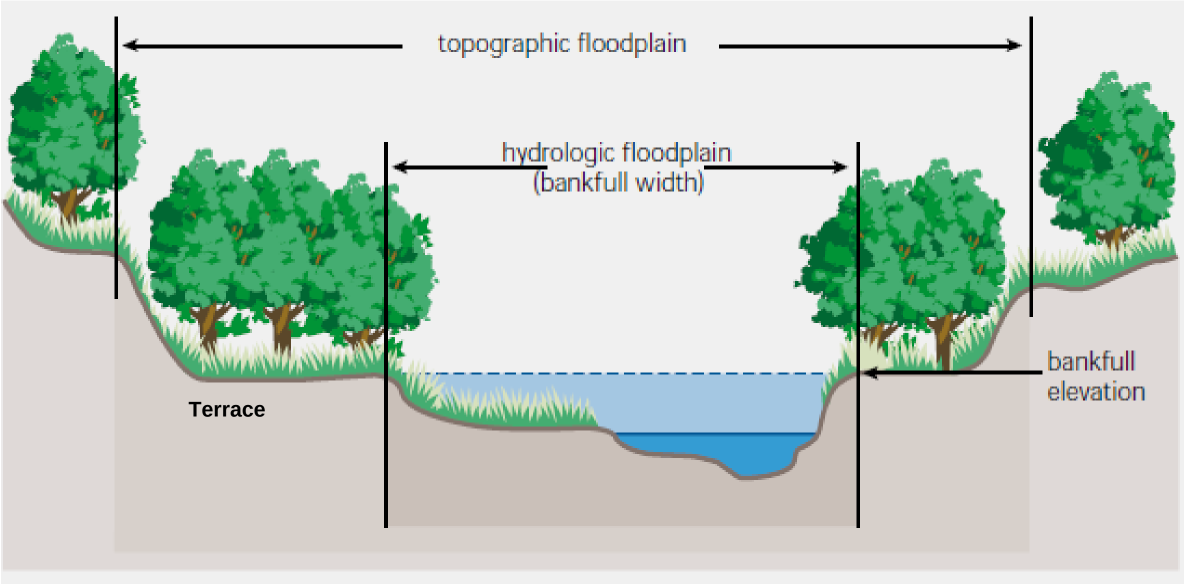


Figure 2.1 Image showing a stream cross-section, and bankfull width and elevation, the topographic and hydrologic floodplain (FISRWG, 1998: 1-18).

The active floodplain is the area that is flooded above bankfull and can be covered with water loving plants (Leopold *et al*., 1964 and Freeman and Rowntree, 2005). The alluvial channel is controlled by bankfull discharges and the identification of bankfull height can be difficult to define when there is little or no active floodplain. The process becomes more subjective as disturbances within the stream channel could give a false impression of bankfull. The bankfull stage is critical in determining flow rates. Indicators found in the field to determine the bankfull level could be misinterpreted, and *where deeply incised streams occur, in which there are no defined terraces and floodplain, experienced practitioners identify other indicators that may serve as surrogates to identify bankfull level* (Harrelson et al., 1994, 33). *Several indicators are used to support the identification of bankfull*; these are outlined below (Harrelson et al., 1994, 33).

The active floodplain is easy to identify along low gradient reaches, but it is almost impossible to identify along high gradient and confined reaches within ravines.

Within these difficult reaches, several indicators can be used to determine the level of bankfull and the active floodplain. These are:

- Height of features of deposition;
- Changes in bank material size;
- Change in slope or topography;
- Height of the bank undercutting, and
- Changes in vegetation and stain lines on rocks or height in lichen on rocks (Harrelson *et al*., 1994; Wadeson and Rowntree, 1994 and Freeman and Rowntree, 2005).

2.2 A Review of Procedures to Determine the Norms and Standards of Geomorphological Assessment

National and international agencies have developed stream characterisation procedures for the monitoring and assessment of the condition of streams. The characterisation procedures are designed to determine the impacts of stream regulation and rehabilitation on the stream's ecological state, geomorphology and riparian vegetation. Fluvial geomorphologists have developed numerous stream characterisation procedures, which characterise the different physical forms found within a stream, for example, pond, riffles and rapids. These procedures are used to understand and track both anthropogenic and natural influences that cause changes in the stream channel morphology (Wadeson and Rowntree, 1994).

Fluvial geomorphologists have developed procedures that describe a stream's physical condition. These procedures are based on assessing the composition of the streambed and physical features that are dependent on the slope or gradient of the stream. These include the physical nature of the stream, and include the surrounding landscape, bankfull, water level, active floodplain, stream channel bottom and the composition of streambed material. The physical features of a stream are somewhat difficult to identify. The composition of streambed materials differs, depending on the slope of the stream (Harrelson *et al.,* 1994; Perry and Vanderklien, and 1996; Rosgen, 1994).

Effective water resource management - including quality assessment, sensitivity ranking and sustainability - demands a stream survey procedure that allows sites to be characterised and significant changes to be monitored (Harrelson *et al.,* 1994; Berman, 2002). Quantifying the existing physical character of a stream forms the basis of geomorphological stream assessment. Harrelson *et al.,* (1994: 1) comment that "*the ability to accurately make and replicate measurements over a period of years"* is important to ensure that applicable data is recorded that can track stream changes over time and changes in personnel.

A stream by its very nature varies and any one type does not end at a point but merges into the next type in a continuous flow (Rosgen, 1994). Types are defined using eight variables outlined by Leopold *et al.,* (1964), which can then form the basis of stream surveys within wadeable streams:

- Width;
- Depth;
- Velocity of discharge;
- Slope;
- Roughness of stream-bed;
- Bank material composition;
- Sediment load, and

- Sediment size.

Rosgen (1994), using these eight variables, divided the stream channel into seven broad stream types at a landscape level, based on slope and dominant channel particle sizes. This classification provides the basis of 41 broad major stream classes. Rosgen (1994) includes further parameters that allow for variations in stream type to be distinguished.

The classification of a stream allows for identification of similar physical features and differentiation of those features that are not the same. Using these classifications and procedures, similar streams can be compared and stream behaviour can be predicted and monitored. Monitoring can be reproducible and consistent, therefore having long-term usage. This allows a wide variety of disciplines to utilise the data, be it environmentalist or hydrologist.

Harrelson *et al.,* (1994) comment that natural stream systems are not random in variation but tend to cluster around the most likely combination of variables based on physical and chemical laws. Changes occur continuously in streams, but these changes tend to move towards a state of channel stability or equilibrium (as discussed in Section 2.1.1). The strongest influencing factor of change in a stream is flow. In changing flow regime, the stream will indicate measurable adjustments along its reach (Rosgen, 1994).

In the next sections, four geomorphological procedures are reviewed.

2.2.1 The United States Department of Agriculture, Forestry Services Geomorphological Stream Monitoring and Assessment Procedure

The United States of America Department of Agriculture (USDA) Forestry Services developed a geomorphological procedure to monitor stream channels within forested areas. The aim of this procedure was to ensure that it is applicable and repeatable when collecting geomorphological monitoring data. The procedure uses a set of basic methods, which identified and yielded quality data at a reasonable cost without a need for a high degree of specialisation (Harrelson *et al.,*1994).

The USDA has developed guidelines for the selection and establishment of geomorphological monitoring reference sites. By the establishment of these sites, data can be gathered and interpreted. From these data, informed management decisions can be made concerning the stream's responses to logging and roads within afforested areas. Thereafter, mitigation measures to limit these impacts and protect the environment can be implemented. This entails careful planning with the objective of understanding the changes taking place within the riverine environment.

The USDA follows guidelines where the objective is to understand the changes taking place within the "bankfull" and the "1 in 10 year" flood-line of a stream (Harrelson *et al*.,1994). The guidelines recommend that the length of the geomorphological monitoring site is determined by any one of the following:

- Distance of one completed meander length, or

- 20 times the stream width, or

- The distance of two complete bends.

Therefore, if a stream has a channel width of 5m, the stream length sampled is 100m (Harrelson *et al*., 1994). By using this scale, the geomorphological monitoring site length and resolution is in proportion to the stream size (Kaufmann, 2001). The geomorphological monitoring sites are set out to allow for repeated measurements, which are documented simply. The geomorphological assessment gives a clear understanding of the rate of erosion or deposition. Although this procedure was developed for the forestry industry, it has been utilised by other agencies to monitor and assess streams (Harrelson *et al*., 1994).

The USDA procedure consists of the following methods to measure and demarcate the rate of change within a stream reach:

- Longitudinal profile survey, which quantifies the channel shape and geometry of a stream along a stream reach. The longitudinal profile survey measures and plots the slope of the water surface, sinuosity of the stream channel, channel slope, flood-plain and terraces, including elevations and positions of stream features (Harrelson *et al*., 1994). The length of the longitudinal profile depends on the objective of the survey. It is recommended a minimum of 274.32 m (300 feet) or 20 times the channel width is measured (Harrelson *et al*., 1994).

- Stream cross-sections are used to delineate channel form at a given point. From this, and measurement of current velocity, the flow rate can be calculated, which may or may not be representative of the stream reach. (Harrelson *et al*., 1994). Cross-sections are measured using a horizontal tape measure across the river to determine the stream width. From this horizontal line, the stream profile or shape is determined by measuring the vertical distance to the streambed at intervals along the line. These distances combine to delineate the stream profile. The vertical points need not be at regular intervals, but when lengths are plotted these should represent change in stream profile (Parson *et al*., 2002). The following are measured along the stream cross-section:

    - Water surface;

    - Edge of water;

    - Bankfull;

    - Channel centre line, and

    - Thalweg, which is defined in the Oxford Dictionary of English as the line of fastest flow along a river's course, which is not always the centre line of the stream (Soanes and Stevenson, 2005).

- Stream forms, bank material, sediment load and sediment size (Leopold *et al.,* 1964). Bed material, consisting of sand, gravel, cobbles and boulders within a designated grid or transect, which should include pools and riffles, are measured. This process uses the technique developed by Wolman (1954), called the Wolman Pebble Count. The streambed material is recorded in accordance with the Wentworth Scale size classes (Wolman, 1954), and

- Stream flow rate, using flow meter or flow gauging weir.

The USDA procedure outlines requirements for setting out a geomorphological monitoring site. These are:

1. Site selection, which is dependent on the survey objectives. The selection is based on the geology, climate, elevation and landuse in the area. This allows for the grouping of streams with similar features based on the assumption that similar streams act in a similar manner.

2. Mapping of the site using topographical maps and aerial photographs. These are used to select geomorphological monitoring sites and identify access routes. In addition, a Global Positioning System (GPS) is used to position features on a map, which are then documented using Geographical Information Systems (GIS) software. A site map is then drawn, which depicts the entire length of the stream to be surveyed. This map outlines terraces, floodplains, vegetation breaks or change, benchmarks (a point of departure or closure for stream measurement), stream cross-sections, longitudinal profiles and other relevant information.

3. Settings of benchmarks for the measurement of stream cross-sections and longitudinal or thalweg profile of the stream channel (Harrelson *et al.,* 1994). A standard method used by surveyors, who require that the benchmark be a permanent point, accessible and identifiable, allows for the repeatable collection of data. Benchmarks are usually located outside the channel/floodplain and could be immovable physical features, but it is common practice to use a survey pin cemented in to the ground (Harrelson *et al*., 1994).

4. Bank erosion pins are iron rods embedded horizontally in the stream bank to measure erosion at that point or used vertically to measure deposition against the stream bank at that point. The orientation of the bank erosion pins relates to flow, sinuosity of the stream channel and observed deposition or erosion. For erosion, the difference in exposed length of the pin between surveys is measured. Similarly deposition is measured by the decrease in height of the pins between surveys (Harrelson *et al*. 1994). These pins are used principally to measure small changes in banks (Harrelson *et al*. 1994). The pins are *fine metal rods between 10 cm - 30 cm long, inserted horizontally at regular intervals into the stream bank* (Harrelson *et al*. 1994, 52). *The elevation of each pin is measured and a standard length is left exposed* (Harrelson *et al*. 1994, 52). The elevation of each pin is measured with a rod and level (Harrelson *et al*. 1994). On successive visits to the site, the length of the exposed pin is measured and recorded; the pin is then driven into the bank (Harrelson *et al*. 1994). Lost pins are recorded and replaced at the same elevation on the bank (Harrelson *et al*. 1994).

5. The development and management of a geomorphological monitoring database is required to document long-term findings, as changes in stream morphology occurs over years and decades (Harrelson *et al*., 1994).

These assessments track erosion and deposition and allow the implementation of restorative measures, track their effect and maintain the stream in an acceptable state. These methodologies also assist in determining the following:

1. The response of the stream to different flow scenarios, for example the water release from a dam on the downstream river;

2. Fluvial and geomorphological conditions, trends and changes in channel morphology (e.g. channel depth and profile, width, bank scour, head-cutting along landslides, debris flows, and area of bank scour);

3. Environmental impacts, loss of riparian vegetation and changes in aquatic biota composition, and

4. Catchment response to the stream's management, landuse and rainfall; and

5. Regional, national and international database resources (Harrelson *et al.*1994).

2.2.2 United States Environmental Protection Agency Geomorphological Monitoring and Assessment Programme

The background to developing the United States Environmental Protection Agency (US EPA) Environmental Monitoring and Assessment Programme (EMAP) procedures for the WSA (Wadeable Streams Assessment) programme was the enactment of the United States Clean Water Act (CWA) in 1972 to protect the nation's vital water resources. A section of the CWA calls for periodic accounting to the United States Congress on the efforts to protect US water bodies. The US EPA EMAP procedure used in this programme is based on the USDA Forestry Services procedure for geomorphological monitoring. The US EPA Office of Water, in collaboration with 66 state environmental and natural resource agencies, developed the EMAP Wadeable Stream Assessment (WSA) procedure. The development of this procedure was in response to the need to determine the state of the national wadeable streams in the USA. In 1994, EMAP developed the Field Operations and Methods for Measuring Ecological Condition of Wadeable Stream procedure, which were revised in 1998.

In 2006, a nation-wide collaborative survey to determine the status of the USA streams took place. The EPA EMAP undertook a Wadeable Stream Assessment, using standardised methods of geomorphological monitoring. The EMAP WSA programme was the first nationally consistent, statistically valid procedure for the assessment of the nation's wadeable streams (Paulson *et al*., 2006). The streams were categorised in accordance with Strahler stream order (stream size) between 1st through 5th order range. EMAP WSA procedures rationale was that the measurement of physical habitat in streams is the basis for understanding of stream biota and stream quality (Paulson *et al*., 2006). Changes in a stream's physical habitat are mainly due to anthropogenic influences, which impact on stream quality. Therefore restoration and maintenance of the physical habitat was seen to be important for improving stream quality.

The objectives of the EMAP WSA procedure are to use methods that are repeatable and easily learnt, to measure and document the physical make up of a stream (Paulson *et al*. 2006). These methods include the following:

1. Determination of a reference condition, also known as the "least-disturbed condition". Paulson *et al.,* (2006, A-2) defines these reference conditions *as "the best available chemical, physical and biological habitat conditions given in the current landscape conditions".* These reference conditions are based on the collection of a wide range of variables (chemistry data and riparian condition) occurring both naturally and as a result of human activities within a catchment. Within this reference condition, random reference sites are selected (Paulson, *et al.,* 2006).

2. Assessment of historical data and information pertaining to the catchment forms the basis for the establishment of the stream monitoring sites (Harrelson, *et al*., 1994; Lazorachak, *et al*., 1998; Paulson, *et al*., 2006). Geology, climate, mapping and other biophysical factors influencing the stream are taken into account. Selection of a site should incorporate variables that are representative of the stream's morphology. These variables

are floodplains, terraces, bars, riffles, and ponds, braided, unconfined and confined channels, and include riparian and adjacent vegetation (Harrelson, *et al*., 1994; Lazorchak, *et al*., 1998; Paulson, *et al*., 2006).

3. Mapping the sites and location (latitude and longitude) using 1:100 000 scale US Geological Survey (USGS) and 1:24 000 USGS maps (Paulson, *et al*., 2006).

4. Sampling reach length is equivalent to 40 stream channel widths, which is based on the premise that *90% of fish species occur within the stream reach* (Lazorchak, *et al.,* 1998. 49). Within this sampling reach, one of the cross-sections which are considered to have a stream profile that has the least changes and obstructions, is called point X. (Lazorchak, *et al.,* 1998). Within this sampling reach length site, 11 equally spaced cross-sections are located; these are used for physical habitat characterization (Lazorchak, *et al.,* 1998). The number of cross-sections has been kept to a minimum for practical reasons. The distance between each cross-section is determined by wetted width, which is the distance between the wetted area on the left bank and the wetted area on the right bank of the stream (Lazorchak, *et al.,* 1998). The wetted width of a stream is described as the area that is damp or wet including the bank. For example, if the wetted width is 2.5m, the length of stream studied is 100m (Lazorchak, *et al.,* 1998 and Paulson *et al.,* 2006). A longitudinal profile is measured (providing a record of the water standing at the time of sampling) at 10 to 15 equally spaced intervals between the cross-sections (100-150 per sampling reach). Included in the sampling reach length, between each cross-section are equally spaced transects. A transect is similar to a cross-section but only the riparian habitat and the longitudinal profile depth are documented. The distance between each transect depends on the wetted width. If the width is less than 2.5m, the transect distance is 1m, similarly if the width is between 2.5m and 3,5m, the transect distance is 1.5m and if the wetted distance is greater than 3.5m the transect distances are 0.01 times the sampling length reach. In a 4m wide stream, the reach or longitudinal length would be 160m and the distance between transects would

be 1.6m (Lazorchak, *et al.,* 1998 and Paulson *et al.,* 2006). At each cross-section the following are measured:

- Bankfull height and width;
- Channel incision height, is defined as *the height up from the water surface to elevation of the first terrace of the valley floodplain (Note this is at or above the bankfull channel height)* (Peck *et al.*, 2001, 129);
- Wetted and bar widths;
- Undercut and bank angle;
- Stream gradient (slope);
- Pool forming features;
- Stream flow rate, and
- Compass bearing (back-sight) (Lazorchak, *et al.,*1998; Peck *et al.*, 2001; Paulson *et al.,* 2006).

5. Analysing the substrate size and type, which is important to fish, benthos and periphyton, is an important indicator as to possible resident organisms and potential stresses (Wolman pebble count, embeddeness) (Paulson *et al.,* 2006).

6. Photographing and compiling a permanent database of salient features at the site that could assist in data assessment and/or interpretation of changes occurring at the site (Harrelson *et al.*, 1994; Lazorchak, *et al.,*1998; Peck *et al.*, 2001. Paulson *et al.,* 2006).

7. Assessing channel-riparian interaction and the complexity of riparian vegetation habitat and cover, which determine stream temperature, organic inputs, channel morphology, niche diversity and cover from predation (woody debris count, fish cover variables). Channel characteristics are altered by riparian and catchment land use, which in turn influence terrestrial-aquatic interactions (bankfull height, incision, sinuosity) (Paulson *et al.,* 2006), and

8. Noting anthropogenic alterations; which are among the markers for diagnosing stream disturbance (Harrelson *et al.*, 1994; Lazorchak, *et al.,*1998; Paulson *et al.,* 2006).

2.2.3 The Australian Geomorphological Stream Monitoring and Stream Assessment Procedures

In Australia, the National River Health Programme, under the auspices of the Cooperative Research Centre for Freshwater Ecology, Environment Australia and the Natural Heritage Trust, developed the Australian River Assessment System (AUSRIVAS) Physical Assessment Protocol (Parsons *et al.,* 2002). The need to assess physical habitats arose from the need to develop a nationally standardised approach to biological assessment of stream conditions using macroinvertebrates, stream morphology and riparian vegetation as indicators. Out of AUSRIVAS, arose the need to refine the existing assessment techniques or develop additional aspects of the river health assessment. One of the sections identified was the physical assessment module, which involved the development of a standardised procedure for assessing a stream's physical condition (Parsons *et al.,* 2002). Interdependencies between the various components of streams seem clear but integrating them is a complex task because of the differences that exist in the disciplines of fluvial geomorphology and stream environment (Parsons *et al.,* 2002).

A hierarchical approach is used, which cascades down the following:

1. Catchment level or watershed (macro scale);
2. Stream system in which climate and geology are considered the major factors that directly or indirectly control physiology and geography of the catchment;
3. Segment system or second or third order stream;
4. Reach system, and
5. Pool and riffle system (Parsons *et al.,* 2002).

The above hierarchical divisions within a catchment provide a representation of a "*complex interrelationship that exists between physical and geomorphological factors across different spatial and temporal scales*" (Parsons *et al.,* 2002: 9). Climate and geology are considered the major factors that directly or indirectly control physiology and geography of a stream and from these two factors all other processes cascade, such as soils, vegetation and microhabitat. These in turn impact on sedimentation and discharge regimes that set the morphology and dynamics of the stream system (Parsons *et al.,* 2002). The changes in stream morphology and behaviour are indicators of changes in flow and sediment regimes within the stream dynamic (Parsons *et al.,* 2002).

The concept of a reference condition is used in this physical assessment procedure. This condition is defined by Reynoldson *et al.,* (1997), in Parsons *et al.,* (2002: 11) as "*the condition that is representative of a group of minimally disturbed sites organised by selected physical, chemical and biological characteristics".* The *"two aspects of the reference condition concept that need to be understood are the coverage of a range of streams and the definition 'minimally disturbed' condition"* (Parsons *et al.,* 2002: 11). Therefore the complete spectrum of stream conditions needs to be occurring at the reference site so that other sites may be assessed. To address these two aspects, the reference condition concept is based at a regional scale on the climatic and geological regions and, within these regions, on geomorphological river types (Parsons *et al.,* 2002). Central to this concept is the 'least disturbed' condition, which is addressed by examining, at both a large and local scale, activities that could impact the stream system (Parsons *et al.,* 2002). Within these reference conditions, reference sites are selected using the following six steps:

1. The identification of broad regions based on climate and geology. This is based primarily on broad rainfall and temperature regimes, and secondly on broad geological regions;

2. The division of rivers into functional zones within each region. These functional zones are identified by geomorphological analyses of the river system. Longitudinal profile of slope, valley character and platform channel pattern are determined by the following:

    - Plotting of the longitudinal profile of the stream, which is altitude against distance from stream source to sea;
    - Plotting of the valley character, which is the valley width against distance from source;
    - The patterns formed along the stream length, i.e. regular meanders, riffles, rapids or braided. These form the planform channel patterns (Parsons *et al.,* 2002);

3. Disturbances surrounding each functional zone are examined, e.g. intensive agriculture, urban areas and afforestation, which are all possible sources of pollution;

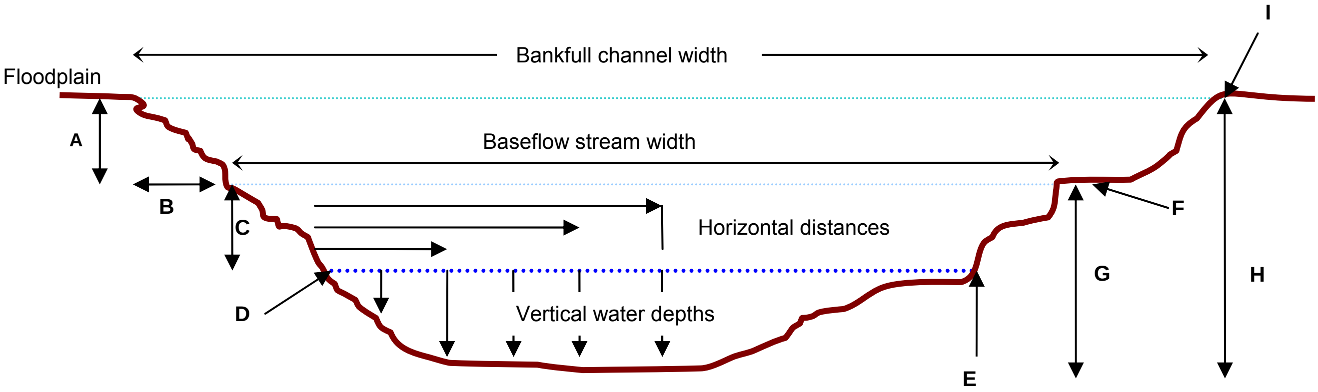
4. The location of AUSRIVAS biological monitoring sites. This biological monitoring site is a stream reach that is considered representative of the stream and is least impacted or changed, and which has all the various different biotypes present. Biotype is a term used to describe the different habitats within a stream such as rocks and vegetation;

5. The identification of least impacted areas within each zone type that occur in each region. The bases for identifying the least impacted site per functional zone is supplemented with chemical, biological and physical surveys and best professional judgement, and

6. The reference sites are stratified equally across all the different functional zones within regions to ensure that the number of sampling sites covers each geomorphological river types. The minimum number of reference sites across all zones within regions is 180. Each reference site needs only to be sampled once as there are no overriding temporal or seasonal aspects for measuring physical and habitat features (Parsons *et al.,* 2002).

The length of a sampling site is a function of the stream size, i.e. 10 times the channel bankfull width.

1. The geomorphological variables measured are:
    a. Physical channel morphology, geology, flood plain features, instream bars and bed-form, valley shape and slope, flow regime, physical stability, bed and bank material, and habitat characteristics, these being bedrock or sand;
    b. Channel shape, which is bank shape and slope, and modifications, artificial features, plan-form channel pattern, which are stream sinuosity, stream stability, sediment matrix and substrate composition;
    c. Stream depth and width, bank height, width and slope, baseflow water mark, refer to Figure 2.2.



Legend

A. Bank Height
B. Bank Width
C. Vertical distance between water surface and baseflow water mark
D. Stream width at the water surface
E. Water surface (at the time of sampling). A tape measure is stretched horizontally across the stream at this level
F. Baseflow watermark. Baseflow mark is the inundated level equivalent to baseflow conditions. This mark is delineated either as edge or boundary of terrestrial vegetation encroachment into the stream, and/or eroded area or break in bank sediment;
G. Baseflow height
H. Channel bankfull height
I. Bankfull level, level is point at the top of the channel where under high flow conditions, water would be even with the top of the bank

Figure 2.2 Components of a channel cross-section measured for the AUSRIVAS Procedure (Parsons *et al*., 2002:141).

2. Geographical influences within the stream catchment are determined by the following:
    a. Surface runoff rates, which are calculated by the mean annual rainfall plus the mean stream slope, and these are linked to the stream's magnitude (determined by the stream order plus all the contributing discharges upstream of the sample point);
    b. Drainage density, this is calculated by dividing total stream length by area of the catchment. This is used to determine the balance between erosive forces and resistance of ground surfaces, and

    c. Stream hydrology, which is the mean annual stream flows plus the seasonal differences, and the stream flow duration curves;

3. Catchment and local landuse assessment, based on riparian vegetation and macrophyte cover that includes the composition, width, type, density and whether indigenous or alien, and

4. Other influences considered are pollution and water quality. Water quality determinants are temperature, pH, electrical conductivity, turbidity, dissolved oxygen, total phosphorus, total nitrogen and alkalinity which indicate the buffering capacity of the water, which in turn relates to geology of the catchment (Parsons *et al.,* 2002).

The placement of cross-sections at the geomorphological monitoring site depends on the components of the streams, planform or channel form. In a uniform or homogenous stream channel form, two cross-sections are required per geomorphological monitoring site, placed at the boundary of the site (Parsons *et al.,* 2002). In a heterogeneous channel form, three cross-sections are measured per geomorphological monitoring site, each being placed at the different channel forms, riffles, ponds and rapids (Parsons *et al.,* 2002). At both uniform and homogenous geomorphological monitoring sites the method states that the cross-section must not be placed at the apex of the bend (Parsons *et al.,* 2002).

Bankfull channel depth and baseflow stream depth are determined based on the average depth for the cross-section (Parsons *et al.,* 2002). Determining the base flow stream depth is an indicator of channel size and this influences discharge capacity within a stream (Parsons *et al.,* 2002).

The procedure clearly outlines the methodology on how to identify physical features, what to measure, and the number of water depth measurement intervals required, between 5 and 15 per cross-section (Parsons *et al.,* 2002). The procedure requires a sketch of the site, which is the stream profile or cross-section channel shape that includes bars, braids, terraces and the baseflow and bankfull level locations (Parsons *et al.,* 2002).

2.2.4 The South African Geomorphological Monitoring and Assessment Approach

In South Africa, the New Constitution that was promulgated in 1996 outlined the concept that water belongs to all. The promulgation of South Africa's National Water Act, No 36 of 1998 (NWA) also recognised that water belongs to all South Africans. Freeman and Rowntree (2005: 66) summarised the NWA as to be able to share water resources fairly between people and the environment, in which *"the concept of identifying the Reserve amount for water was developed. This reserve takes into account the flow and water quality needed to meet the basic needs of South Africans (e.g. sanitation, health, survival= the* ***Basic Human Needs Reserve****), but also accounts for the need of the aquatic systems (e.g. River environments =* ***the Ecological Reserve****).* In the development of an Ecological Reserve for the protection of aquatic ecosystems, hydrologists, ecologists, and geomorphologist have set in place procedures known as Resource Directed Measures (RDM). The RDM process focuses on maintaining an acceptable flow regime downstream of impoundments that would maintain the ecosystem in an acceptable state (Rowntree and du Plessis, 2003). In the context of RDM, the role of the geomorphologist is therefore to determine how stream regulation can imitate the natural fluctuations to a degree that will keep the river environment in a sustainable condition (Freeman and Rowntree, 2005). In line with the RDM, the Building Block Method (BBM) was developed. The BBM, is based on *"the concept that a stream ecosystem is adapted to a range of flows"* (Rowntree and Wadeson, 1999: 273) and centres on the formulation of a stream flow regime to protect the aquatic biota and the demands of the downstream users. This flow regime is determined by employing specialist scientists with knowledge of the stream in question. They develop a modified flow regime that will facilitate the maintenance of the stream to a predetermined condition, taking into account the needs of local communities and stream abstractors (Newenham and Chavalala, 2003). This methodology became known as the Instream Flow Requirement (IFR) that specified the criteria for the quantity of flow, (in particular low flow), volume and timing of releases (Rowntree and du Plessis, 2003).

In determining the IFR for a stream system on which stream regulation is to be undertaken, a number of sites are identified using the hierarchical geomorphological model approach (Rowntree and Wadeson, 1998). The geomorphological hierarchy cascades down the following:

1. Catchment level, the entire area on which rainfall runoff and sediments contribute to the stream (macro scale);

2. Zone, areas considered homogenous, having similar rainfall, runoff and sediment production;

3. Segment, a length of stream channel with no important change in either flow or sediment load, comprising uniform channel forms;

4. Reach, a length of stream channel that comprises riffles, pools and cascades, having a uniform geomorphological component (unit) or a number of geomorphological components that combine to form a group;

5. Geomorphological unit (channel morphology) commonly identified by geomorphologists i.e. rapids, pools and riffles; and

6. Hydraulic biotope, a term used to describe specific flow type and substratum combinations (Rowntree and Wadeson, 1998).

The IFR monitoring procedures are based on five broad components:

1. Geomorphological method developed by Rowntree and Wadeson (1998), which is applicable to all types of biomonitoring programmes. This method consists of over 20 sub-components, which describe the different reach type, channel plan and dimension, instream vegetation, morphology

characteristics, bank and stream material and any anthropogenic modification of the stream (Newenham and Chavalala, 2003); The geomorphological monitoring site assessment consists of determining the following:

- Channel plan, indicating different geomorphological features;
- Historical flow data, present flow rate and water level at the time of sampling;
- Cross-sections, with a minimum of 3 per geomorphological monitoring stream reach or site as outlined above, spaced one channel width apart, in which stream dimensions, bankfull level, lowest longitudinal profile (described as the lowest water level that a stream will flow), and active channel are determined (Dollar and Rowntree, 2003). Other physical features measured, i.e. bars and boulders, riparian vegetation, benches and terraces, are indicated;
- Dominant geomorphological unit, pools or riffles, which in turn helps to classify the stream reach type;
- Transect, a 10m river length that is used to measure stream flow, accurately depict geomorphological features, and determine average flow depths and velocities;
- Bank and bed materials, size and distribution and bank stability and erosion, bar types and channel modifications, and
- Photographic record of geomorphological monitoring stream reach which consists of cross-sections, dominant geomorphological unit, pools or riffles and other features that could assist in understanding the stream characteristics (Rowntree and Wadeson, 1998; Newenham and Chavalala, 2003).

2. Riparian vegetation assessment, by using line transects through the survey site. The transect line extends by approximately 5m from the water's edge into the riparian zone and 10m along the stream channel length (Newenham and Chavalala, 2003);

3. A rapid biomonitoring assessment is undertaken using the South African Scoring System version 5 (SASS 5);

4. The collection of a fish population sample using an electro-shocker and various sized nets, sampling each different habitat within a timed period, and

5. Water Quality monitoring and assessment, which includes analyses for phosphorous, nitrogen, suspended solids and turbidity (Newenham and Chavalala, 2003).

In the next section, a summary of the norms and standards used in the four geomorphological monitoring procedures reviewed above are outlined.

2.3 Norms and Standards for Geomorphological Assessment derived from the Reviewed Procedures.

The four procedures, IFR, AUSRIVAS, USDA guidelines, and EMAP WSA, reviewed in this dissertation were all found to have a strong geomorphological component. These procedures utilise similar methodologies to measure and assess stream morphology, and the goals of each are to assess the health, physical habitat and structure of a stream.

The four procedures are all a result of a collaborative effort by government agencies, universities and the private sector, and were developed through a rigorous review process. Each of these procedures is based on the premise that individual measurements and visual assessments combine to form an overall understanding of the impact and magnitude of change, or lack there of, within the stream environment. These procedures are repeatable as there are clearly defined points to measure. These procedures all require a certain level of expertise to collect and analyse the data and information collected. From the four geomorphological monitoring procedures reviewed in this dissertation, the following norms and standards of assessing stream morphology were derived:

1. Cross-sectional profile: All the procedures reviewed use this as a core method of stream assessment. Each procedure reviewed uses a different number of cross-sectional profiles per geomorphological monitoring site, but generally at least two are recommended. The IFR uses three cross-sectional profiles per site spaced at a distance of one stream width apart (Dollar and Rowntree, 2003). The AUSRIVAS procedures base the number of cross-sections per geomorphological site on the heterogeneity of the stream channel. A homogenous stream channel has two cross-sectional profiles and a heterogeneous stream channel has three cross-sectional profiles (Parsons *et al*., 2002). The USDA procedure does not prescribe the number of cross-sections per geomorphological monitoring site but a single cross-section is mandatory and additional cross-sections can be added depending on the objectives of the study (Harrelson *et al*., 1994). The EMAP WSA procedure outlines that 11 cross-sections are mandatory and form part of the longitudinal stream profile (Lazorachak *et al*., 1998 and Kaufmann, 2001). The measurement of the cross-section profiles indicates the shapes of the stream channel at a single point. These profiles are used in conjunction with series of measurements that indicate the following:

    - Width of the flood plain;
    - Bankfull depth and width;
    - Height of terraces;
    - Depth of channel;

- Discharge rate;
- Velocity of stream;
- Height of water surface and width, and
- Physical features e.g. the sediment composition and riparian vegetation (Lazorachak *et al*., 1998 and Kaufmann, 2001).

2. Longitudinal profile: The measurement of the longitudinal stream profile is recommended in the IFR, AUSRIVAS, USDA guidelines, and EMAP WSA procedures and, combined with the number of stream cross-sections and transects or intervals, map the stream profile along a reach of a stream. This profile indicates change occurring within a stream reach, various habitats, streambed slope and composition, riffles and pool. The EMAP WSA procedures use a number of transects between each cross-sectional profile from which to derive the longitudinal profile.

3. Stream discharge rate: The determination of the rate of discharge in a stream (m^3/s), which is considered to influence the geomorphology of streams by all the procedures reviewed. This variable impacts upon the erosion and deposition potential, which influences the sinuosity and longitudinal profile of a stream.

4. Mapping: All of the procedures recommend that a graphical representation of the stream reaches is made showing the cross-sections, longitudinal profile and important geomorphological characteristics, i.e. riffles, rapids, cascades, and falls.

5. Photographs: Aerial and onsite photographs of the site are considered an asset that could assist in data assessment and interpretation of changes occurring within the stream. Photographs are considered to be the most basic form of monitoring, revealing and identifying changes that

measurements miss and document historical record of a site. The USDA, IFR, USEPA WSA and AUSRIVAS consider onsite photographs of the site to be an asset assisting in data assessment and interpretation of changes occurring within the stream. The USEPA WSA and AUSRIVAS include photographic benchmarks from which images are collected of the site. The USDA requires that all the details pertaining to the camera are documented, that is the type (film, slide or digital) and lens size.

In addition aerial photographs enable researchers to undertake the following:

- A visual assessment of the vegetation and other important features within the stream reach both upstream and downstream of the geomorphological monitoring sites.

- Document changes which occur over an extended time frame; and

- Give an indication of the fluvial geomorphology both upstream and downstream of the site, which influences the rate and location of bank erosion, and *temporal changes in those rates and location* (Thorne, 1981: 507).

Thorne (1981: 507) states, *“Supplementary data from aerial photographs and historical maps are invaluable in putting a detailed field study into context of larger scale and longer term channel changes”*

In conclusion, the procedures reviewed in this dissertation i.e. the IFR, USEPA WSA EMAP and AUSRIVAS do not use bank erosion pins to measure bank erosion. However the USDA procedure, states that these are used infrequently and when used, monitor sites at which erosion is expected to be on a limited scale (Harrelson *et al*., 1994).

The various monitoring procedures reviewed have similar basic geomorphological monitoring methods. These methods are linked together to determine the rate and magnitude of change within a stream. Each of these three methods reviewed can "stand alone" but they have limited application. When all three methods are combined they form a "picture" of the stream reach and as previously stated can determine change.

The cross-sectional area and using a current meter determines the velocity of the stream. These are considered to be the most important variables, which impact on the rate of erosion and deposition within a stream. The change in flow regime is manifested in the change in stream morphology and behaviour, altering the planform channel pattern, and sediment load.

3. RESEARCH METHODS AND STUDY SITE

The investigation for this dissertation focused on the Mpofana stream and Lions River, also known as the “receiving streams” of the Mooi-Mgeni Transfer Scheme (MMTS-1). The area is illustrated in Figure 3.1. Four aspects are considered as follows:

- The general methodology used in the study;

- The specific methods applied in the study, which were used to evaluate the MMTS-1 geomorphological monitoring procedures to monitor the geomorphological impacts on the receiving streams, during the period November 2002 to July 2006;

- A description of the consecutive planning reports, assessment and recommendations for the MMTS-1, and

- A description of the procedures used in the MMTS-1 to monitor the geomorphological impacts on the receiving streams, during the period November 2002 to July 2006.

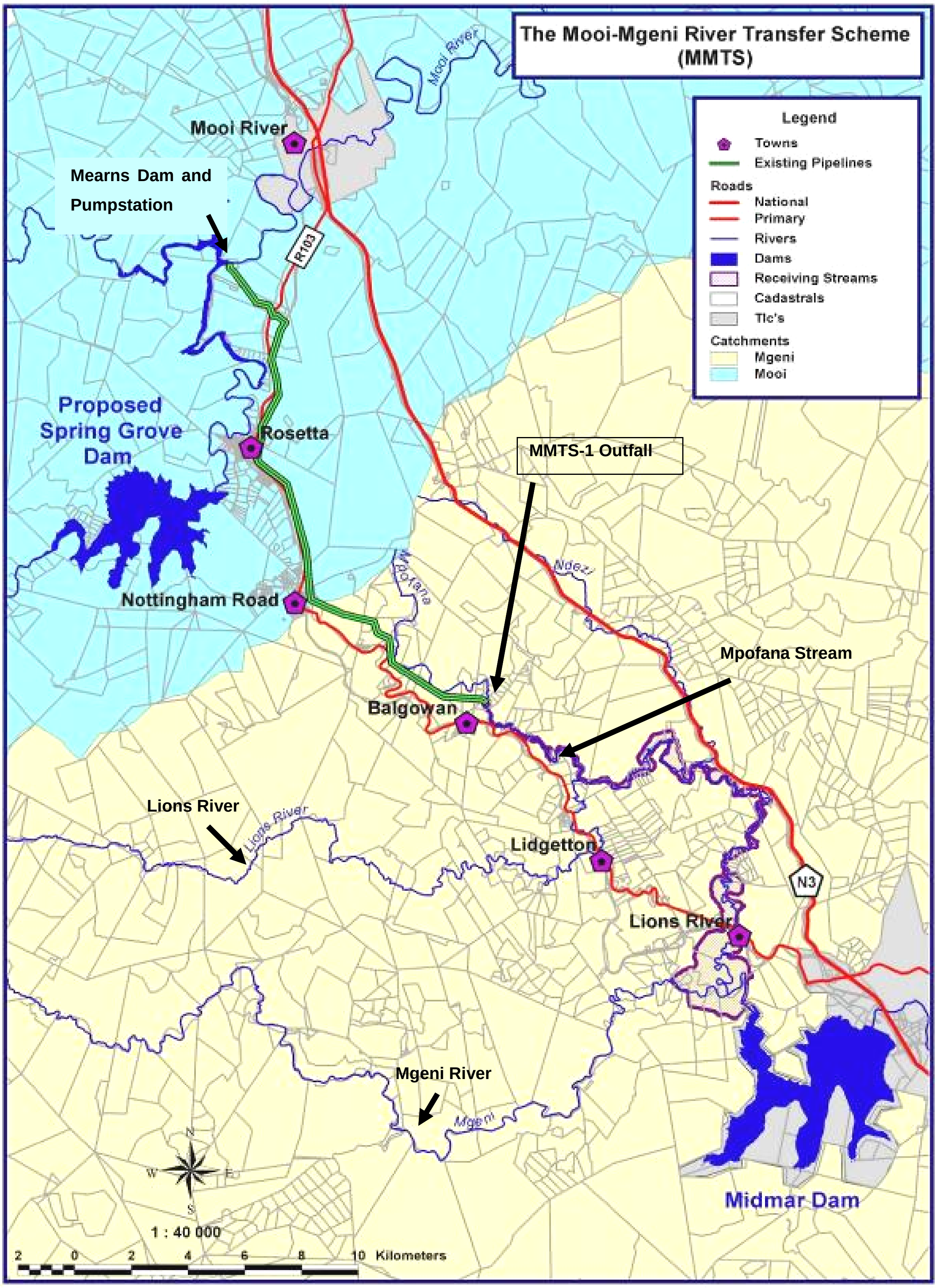


Figure 3.1 Locality of the receiving streams, Mpofana, Lions and Mgeni Rivers and Mearns dam site (Huggins, *et al*., 2002).

3.1 Methodology

A qualitative observational study design was adopted for the review of the geomorphological monitoring of the receiving streams. Qualitative observational research is based on the researcher's observations as the principle method of data collection (Leedy, 1989). When implementing an intervention in a natural setting, the researcher observes and describes any changes that occur within a stream (Zailinawati *et al*., 2006).

This method is susceptible to distortion due to the introduction of a bias in the research design by the researcher. To combat this bias as far as possible, the parameters in this study were limited to the stream geomorphological monitoring procedures, data collected from the erosion pins, stream cross-sections and fixed point photography. Furthermore, these parameters were assessed against criteria used in the norms and standards of geomorphological stream assessment which have been developed and implemented by national agencies in Australia, United States of America and South Africa, and have been peer reviewed using sound scientific principles to determine and track changes occurring within a stream.

3.2 Methods

The following activities were conducted to address the objectives of the study:

1. A desktop review of literature covering norms and standards used for stream geomorphological assessment. This review described stream geomorphological assessment procedures outlined by national agencies and state departments that have developed standardised procedures based on a qualitative approach to the physical assessment of stream condition (Parsons *et al*., 2002). This has been documented in Section 2.

2. An assessment of the erosion monitoring procedures from the MMTS-1 receiving stream, as outlined in the Environmental Management Plan, and the implementation thereof including:

- An assessment of how well the erosion monitoring procedures complied with the norms and standards for stream geomorphological assessment described in Section 2.3;

- An assessment of the implementation of the erosion monitoring procedures based on an evaluation of the bank erosion pin measurement, relocation and replacement;

- An evaluation of the fixed-point photography, their collection and limitations;

- A comparison of the implementation of erosion monitoring procedures for the receiving stream of MMTS-1, with norms and standards used in three national geomorphological monitoring procedures and assessment of streams, and

- An appraisal of the competency of the personnel collecting and evaluating the erosion monitoring data.

3. Recommendations for improving the erosion monitoring procedures and the effectiveness of their implementation based upon the findings of the study.

In terms of statistically analysing the erosion pin data, the number of pins, following extensive loss of pins, was considered inadequate for statistical analysis, and therefore of limited value to draw statistically meaningful conclusions about the rate of change in the receiving streams.

It is recognized that the institutional arrangements and environmental monitoring that consist of water quality monitoring; aquatic invertebrate and vegetation assessments are critical. However, all of these components are considered to be beyond the scope of this review.

A summary of the environmental studies conducted to assess the impacts of the MMTS-1 is given in the following section. This provides context to Section 3.4, which describes the details of the erosion monitoring procedures from the MMTS-1 receiving streams.

3.3 Environmental Studies Conducted between 1984 to 2001 to Assess the Impacts of the MMTS-1 on the Geomorphology of the Receiving Streams

Several studies have been carried out to investigate the potential impacts of he transfer scheme on the receiving environment and these are listed in Table 3.1 below.

Background	Project Description	Date	Organisation	Capacity / Operation
Need for the implementation of an emergency response to 1984 drought required implementation of a transfer scheme. No planning study found.	Mearns Emergency Transfer Scheme constructed.	1984	Umgeni Water	Built for 3.2 m^3/s but only used 1.6 m^3/s due to environmental and social constraints during two drought periods: 1984-1985 and October 1993 to December 1995 (Henderson, 1995: a)
Need to investigate the social and environmental issues associated with the MMTS-1 impacts on the Receiving Streams.	MMTS Receiving Rivers Impact Management Study and workshop report.	1995	SRK	The study assessed the impact of the transfer of 6 m^3/s (Henderson, 1995: a).
Development of an environmental management plan for the proposed transfer scheme.	MMTS-1 Receiving Rivers Impact management Study Volume 7: Environmental management Plan.	1995	Keeve Steyn	Proposed environmental management plan for the transfer of 3.2 m^3/s to 6 m^3/s, which considered a brief transfer period of 10 m^3/s (Henderson, 1995: b).
Need to upgrade the emergency response scheme. Feasibility study commissioned.	Mooi-Mgeni Transfer Scheme Feasibility Study: Mooi-Umgeni Transfer Scheme Environmental Impact Assessment.	1996 1996	Keeve Steyn SRK	The impact of 3 transfer options were investigated, namely 3, 6, and 10 m^3/s transfer (Keeve Steyn, 1996).
Post NEMA legislation need to formalise EIA application associated with the MMTS-1.	MMTS-1 Receiving Streams EIA.	2002	Umgeni Water	Impacts of transfer of up to 4.5 m^3/s (Umgeni Water, 2002).

Table 3.1 History of the MMTS-1 Receiving Streams studies: The planning journey

The receiving streams studies undertaken during the period 1984 to 1996 highlighted that the environmental impacts on the receiving streams by the MMTS-1 transfer. All these studies proposed several transfer options to limit the long-term impacts but had no environmental monitoring strategy from which flow management decisions could be made (refer Table 3.1).

3.3.1 Environmental Impact Assessment - MMTS-1

In 1997, legislative requirements changed for infrastructure development with the identification of activities that would have a detrimental effect on the environment. These activities were identified in Schedule 1 of South Africa's Environmental Conservation Act, 1989 (No 73 of 1998), Section 21, Government Notice (GN) R. 1182 and the regulations regarding activities identified under section 21 (1) of the Act, GN R.1183 outlined that authorisation is required from Department of Environmental Affairs and Tourism (DEAT) to undertake any of the scheduled activities. In GN 1182, sub-regulation (1) (i) and (j) of the Act, and in accordance with ECA, 1989 Sections 26 and 28, GN R1183 sub-regulation (5 and 7) the construction of Mearns dam and the interbasin transfer of water are scheduled activities. Therefore, in line with GN 1183, the MMTS-1 required the development of a Scoping Report and a result of the findings of this report, an Environmental Impact Assessment (EIA) was undertaken. A Scoping Report is a brief description of the activity and identifies environmental issues and alternatives. An EIA assesses the impact on the environment of the activity and identifies environmental issues and proposes possible alternatives (refer Table 3.1). The EIA for this scheme required the approval of DEAT.

The EIA report for the Mooi-Mgeni Transfer Scheme: Receiving Streams Environmental Impact Assessment (Huggins, *et al*., 2002) highlighted the possible environmental impacts of the transfer of water on the receiving streams. The findings and recommendations from the EIA relevant to this study were:

1. The monitoring of erosion in the receiving streams, and the identification of vulnerable sites or "areas of concern" which are sites with high erosion potential (Huggins, *et al.,* 2002). Areas of concern were identified in this study using a simple geomorphological classification system, which identified sections of the receiving stream that may require remediation (Huggins, *et al.,* 2002). *The classification system used is widely accepted and used in South African rivers* which *considers the degree of*

geomorphological change from the theoretical "reference condition" (Wadeson, 2003: 7).

2. There would be a marked change in the stream channel morphology but after a period of transition of elevated erosion within the stream, it would reach a state of equilibrium. Thereafter there would be a reduction in the erosion of the receiving stream (Huggins, *et al.,* 2002).

3. That a more or less constant flow regime would minimise bank instability problems and ameliorative engineering measures. These measures included control structures in confined sections and bank protection measures in unconfined alluvial areas.

4. The transfer pumps should not exceed 4.5 m^3/s, as higher pump rates would pose a threat to bridges and cause inundation of the stream's flood plain, and

5. The MMTS-1 was not to operate during high flow periods (Huggins, et al., 2002).

The MMTS-1 EIA concluded that there were no fatal flaws and that the transfer scheme could proceed. In the EIA process, the Record of Decision (RoD) issued by DEAT for the MMTS-1 outlined requirements that would manage the impacts of the transfer on the receiving streams (Huggins, *et al.*, 2002). From this EIA report, an Environmental Management Plan (EMP) was developed to manage and monitor the environmental impacts for the construction and transfer phases of the Mooi-Mgeni Transfer Scheme Phase 1 and implement remedial measures to mitigate against the environmental impacts.

The management measures that were recommended in the RoD were:

1. Active and passive anti erosion control measures;

2. Flow management;

3. Restoration of physical access points that are possibly lost;

4. Appropriate levels of compensation for those suffering losses, and

5. An ongoing adaptive management and monitoring programme.

The RoD recommended that a biophysical monitoring programme be implemented to assist the management of this interbasin transfer and reduce degradation of the receiving streams.

3.3.2 Environmental Management Plan- MMTS-1

The Environmental Management Plan (EMP) outlines the activities associated with the operational phase of the project with specific reference to the receiving streams. In DEAT's RoD, reference no. A24/16/3/209, conditions to monitor the environmental impacts of the MMTS-1 on the receiving streams were outlined. The DEAT RoD requirements incorporated into the EMP for MMTS-1 have two components and these are (Huggins, *et al.*, 2002):

1. An Environmental Working Group (EWG), consisting of various stakeholders, including Umgeni Water, whose role is secretarial and maintains the geomorphological monitoring database. The EWG's role is to manage the implementation of the EMP for determining the impacts of the transfer on the receiving streams and, where necessary, implement the appropriate mitigatory measures (Alletson, 2002).

2. Implementation of the geomorphological monitoring programme, which is a core requirement of the EMP for the MMTS-1 (Alletson, 2002).

The geomorphological monitoring programme specialist study for the MMTS-1 EMP proposed twenty-one sites. The survey sites were divided into three different categories and are as follows:

1. Erosion pin reference sites, which are control sites, at which both erosion pin and a cross-section are measured. The sites are on the Mpofana stream, upstream of the MMTS-1 outflow (M1) and the Lions River upstream of the confluence with the Mpofana stream (L1);

2. Erosion monitoring pin sites at which erosion pins were measured (M2, M3, M6, M7, M8 M11, L3, L4, L5, L6 and L7) of which only nine of these sites had deposition pins (M1, M2, M3, M6, M7, M8, M11, L4 and L6);

3. Cross-section were measured at six sites (M3, M7, L3, L4, L7 and L8), and

4. Reference sites at which photographs and onsite observation were recorded at eight sites (M4, M5, M9, M10, L2, L8, L9 and U1) (Figure 3.2) (Alletson, 2002 and Wadeson, 2003).

The sites selected provided "*a broad range of morphologies and included many potentially sensitive locations"* (Wadeson, 2003: 4). It was stated that onsite photographs should be taken at all sites (Alletson, 2002). The procedure was documented in "The Implementation of Geomorphological Monitoring for MMTS-1 Receiving Streams" produced for Umgeni Water (Wadeson, 2003). The responsibility for monitoring and maintenance of the database would then be undertaken by Umgeni Water personnel and as part of capacity building and training (Alletson, 2002).

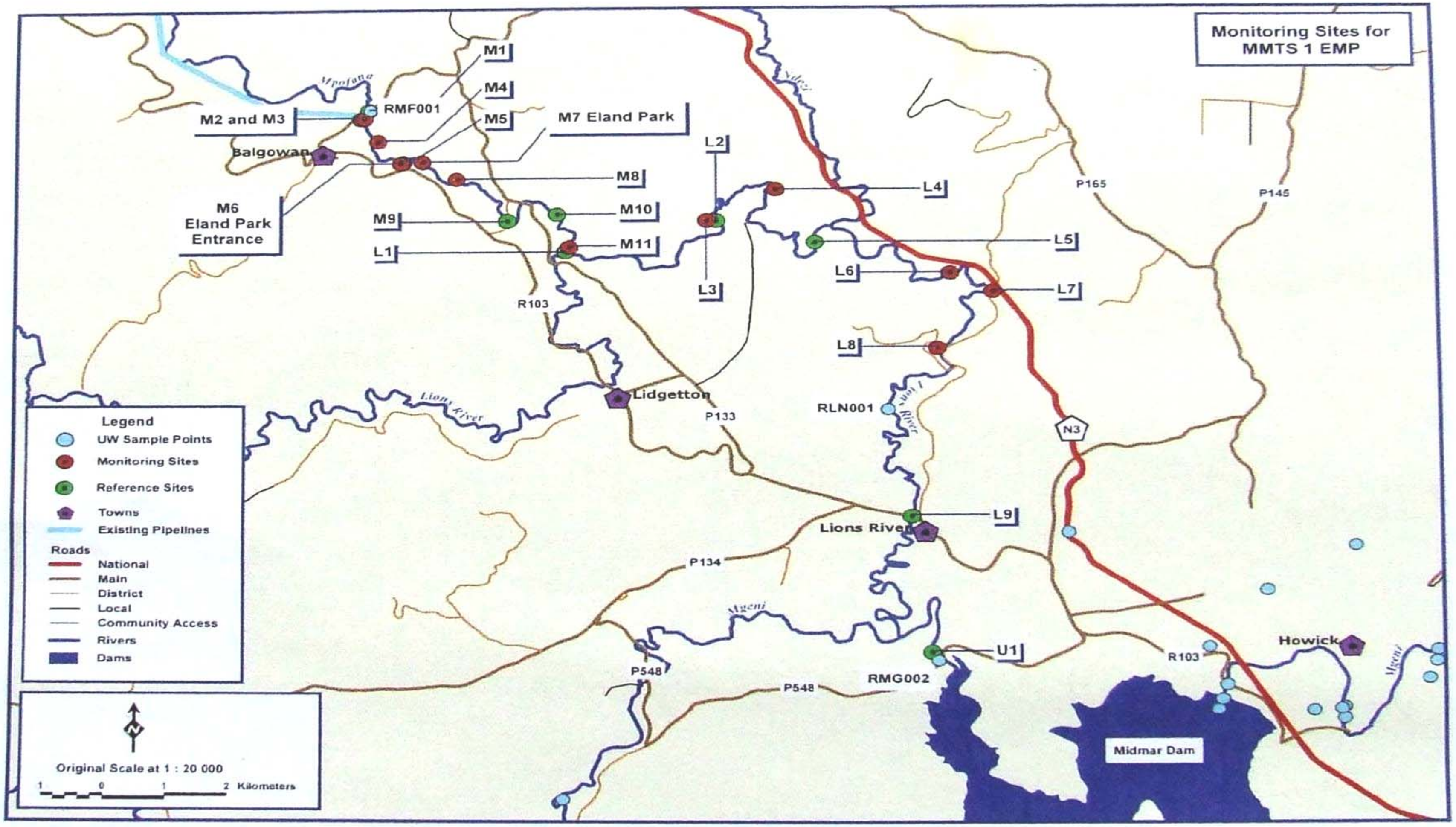


Figure 3.2 **Map showing the locations of the geomorphological monitoring sites (Huggins, *et al*., 2002: 21).**

The geomorphological monitoring programme (Alletson, 2002 and Wadeson, 2003) consists of four basic methods to determine physical change, and these are:

1. Placement of bank erosion pins, horizontal or vertical metal pins hammered into the stream bank from which the amount of soil lost or gained is indicated by the difference in the exposed length of the pin from the previous survey.

2. Cross sectional survey, in order to determine the profile of the stream channel;

3. Fixed-point photography, a photographic record taken from a fixed point of a section of the stream bank, and

4. On-site observations, noting changes that have occurred, be it bank slumping, vegetation loss or damage to bridges and infrastructure at the sites as a result of the MMTS-1 on the stream channel.

3.4 Techniques and Procedures for Monitoring the Geomorphological Impacts on the MMTS-1 Receiving Streams

The fluvial geomorphological monitoring programme began in November 2002 with the identification of sites for the placement of the erosion pins and stream cross-sections. Wadeson (2003) outlined the geomorphological conditions for selecting geomorphological monitoring sites, the locations of which are given in Figure 3.2. At each site the following geomorphological conditions were assessed:

1. Valley form, the shape of the surrounding valley, gorge or floodplain (Parsons, 2002);

2. Geology, describing the make up of the streambed i.e. whether dolerite or sandstone and if there are dykes or faults;

3. Channel impacts and geomorphological classification; describing geomorphological change and the degree of change from a theoretical “reference condition” to a critically modified condition in accordance with a widely accepted South African rivers geomorphological classification method (Wadeson, 2003);

4. Channel planform or pattern, describes the stream channel whether it is sinuous, narrow or wide, braided or meandering;

5. Channel type, describing the channel and bedrock whether it is alluvial or bedrock and if there are boulders, gravel, sand and silts;

6. Bed material/bed packing, describing the size and nature of the material, be it cobbles, gravel, sand or silt and if it is loosely or tightly packed;

7. Morphological units and reach types, describing whether a pool, rapids or riffle dominated channel morphology;

8. Vegetation condition describing the state of the riparian vegetation and its coverage, be it sedges, grasses or trees;

9. Bank stability/bank erosion, describing the state of the banks, whether erosion has caused undercutting and slumping, and

10. Habitat condition, describing the instream hydraulic condition, its stability and hydraulic properties (Wadeson, 2003).

Of the erosion monitoring sites (13) selected, two were designated as erosion monitoring reference sites, one located upstream of the MMTS-1 outfall (M1), and --the second in the Lions River upstream of the Mpofana-Lions River confluence (L1).

In the following section the method of data collection is described.

3.4.1 Erosion Pins Placement and Monitoring

Erosion pins are a series of iron rods 60 cm in length embedded horizontally in the stream bank to measure erosion at that point and a 120 cm rod set vertically into the stream bed against the stream bank to measure deposition at each site. Pins are set horizontally into the bank on a diagonal line to allow for the determination of erosion potential along the vertical plane and allow for undercutting or bank collapse to occur without losing the adjacent pins (Figure 3.3 to 3.5) (Wadeson, 2003). The objective was to measure the erosion at a single point on the stream bank. The difference in exposed length of the pin between surveys indicates the amount of erosion or deposition that occurred between surveys.

Of the twenty-one geomorphological monitoring sites, thirteen were identified as sites having the greatest potential for erosion and at these sites, bank erosion pins were placed (see Section 3.3.2). As previously stated, two erosion monitoring sites, one located upstream of the MMTS-1 outfall in the Mpofana stream and a second located in the Lions River upstream of the Mpofana-Lions River confluence, are control sites. These are used as a comparison with the downstream stream erosion pin sites. The remaining eight reference sites were identified as being sites where erosion would occur and where fixed-point photographs would be taken to record change.

Prior to the completion of the MMTS-1, in February 2003 and before commencement of the first transfer operation, the erosion pins were set at the thirteen predetermined sites. Each site had the required number of erosion pins hammered into the stream bank and deposition pins located in the area, where deposition was anticipated.

The erosion pin data were collected during the period between transfers. The exposed length of the erosion pin was measured using a metal meter rule and data recorded manually. Thereafter the data were transferred into an electronic database spreadsheet (Windows Excel) on the Umgeni Water database. To determine extent of change or erosion per geomorphological erosion pin, this was calculated by the difference in lengths per pin from the previous survey. This gave either a positive or negative figure, per pin. A positive figure indicated that deposition had occurred and conversely, negative figure indicated that erosion had occurred. The accumulated distance eroded or deposited was determined by adding the average difference in length per pin per survey.

With subsequent erosion pin surveys, the erosion pins were located, measured, labelled with markers and fixed-point photographs were taken. Erosion pins lost were replaced in approximately the same location. Erosion pins that had been partially buried in the streambed sediment or had fallen onto the streambed were reset in approximately the same place. Typical examples of the different distribution of erosion pins to determine the horizontal and vertical erosion profile of the stream bank are seen in Figures 3.3 to 3.5.

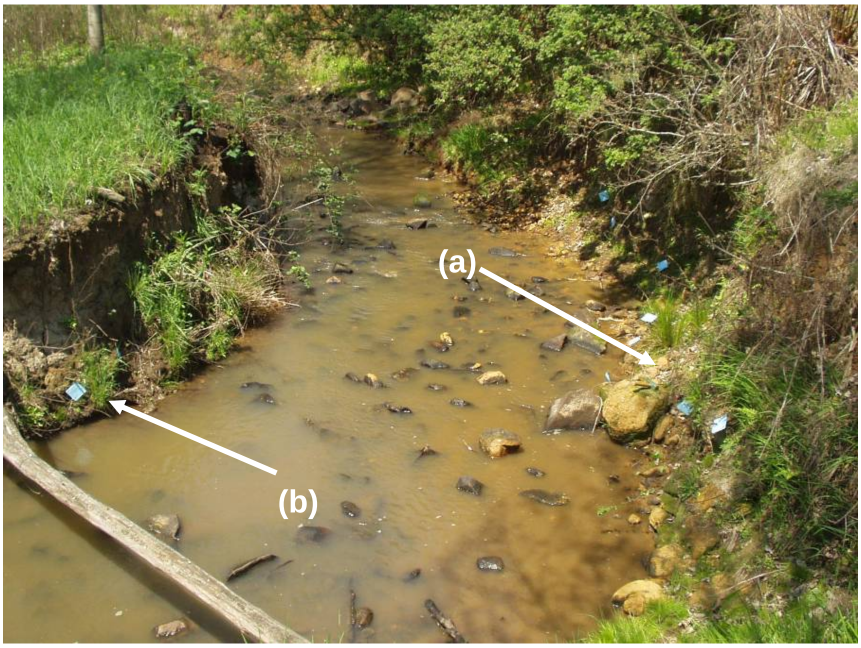


Figure 3. 3 Site M3, an example of the location of both erosion (a) on the outside stream bend and deposition pin (b) (blue markers) on the inside stream bend.

Figure 3.4 Typical erosion pins site (L3), an example of the distribution of pin (blue markers) along horizontal profile of the stream bank. The arrow indicates where bank slumping has occurred.

Figure 3.5 The resetting of deposition pin on the inside of the stream bend at Lions River at the pump-house (L4).

Staff Training

No training in assessing the erosion pin monitoring occurred prior or during the period under review. There was briefing on the method for erosion pin measurement and assessment proposed by Wadeson (2003), which was not communicated to the technician undertaking the erosion pin monitoring.

3.4.2 Stream Cross Section Establishment and Monitoring

A land surveyor employed by Umgeni Water during the period 2002 to 2005 carried out 4 cross sectional surveys. Eight sites were chosen from the twenty-one geomorphological monitoring sites as outlined in Section 3.4, at which cross-sections were measured. Six of these had erosion pins located next to the sites. The surveys were carried out using standard survey procedures, and the stream width was measured using a standard survey measuring tape. Then using a Dumpy level, at the bankfull height, the slope or shape of the stream channel was "mapped" by measuring the depth of the stream at different intervals in accordance to the change in the slope of the channel (Figure 3.6). These measurements were then graphed to depict the stream profile using a Computer Aided Design (CAD) programme. The data was then downloaded onto the Umgeni Water database.

The pre-transfer cross-sectional survey was undertaken in November 2002, and then three post transfer cross-section surveys were undertaken during the period September 2003 to June 2006. The surveys were taken from the tops of the stream banks to the tops of the other side of the stream.

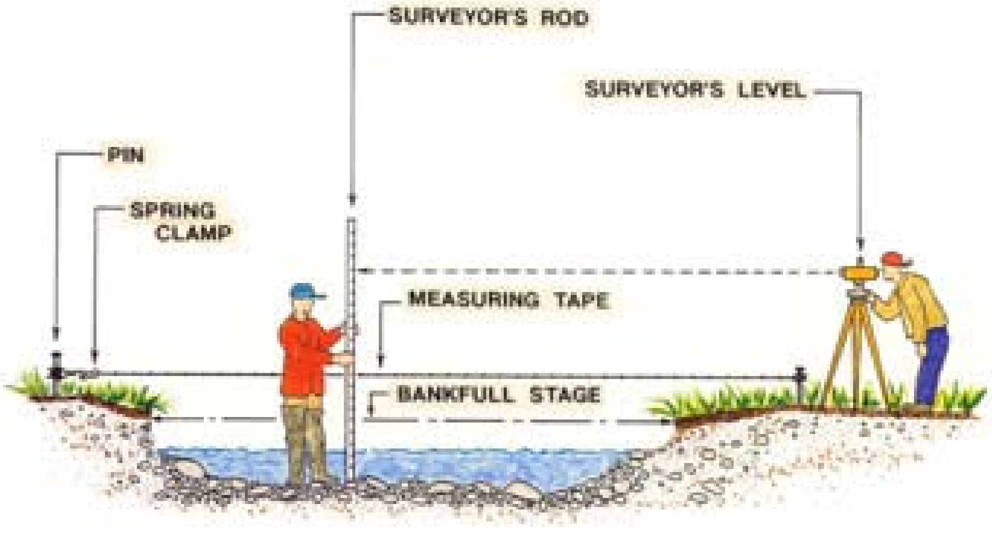


Figure 3.6 Diagram of Surveyor measuring a stream cross-section (Rosgen, 1996 in Babbit, 2005: 15)

Fixed-Point Photography

The fixed-point photography was implemented to supplement the information obtained from the geomorphological erosion pins. The procedure was to photograph each site at which erosion pins had been placed from a fixed point or benchmark. The benchmarks were marked with white enamel aerosol spray-paint by the placement of either a cross or mark on a tree or fence post.

The Wadeson (2003) report outlined that all twenty-one monitoring sites required photographs to be taken during each erosion monitoring survey. During the geomorphological surveys undertaken in the period 2003 to 2006, only thirteen erosion sites were photographed.

Photographs were transferred into the Umgeni Water database and arranged in chronological order to show the changes occurring at each erosion pin site.

Aerial Photography

There have been two sets of aerial photographs taken. The first was taken in 1995 at a scale of 1: 6 500 as part of the initial Receiving Streams study undertaken by Keeve Steyn. The second set of aerial photography available for the area is the 2001 aerial photography, which was taken by the Surveyor-General (Chief Directorate of Surveys and Mapping) as part of their programme of providing recent aerial photography for the entire country. This was at a scale of 1: 30 000, which is too small to identify changes that have occurred within the receiving stream channel. Although the aerial photography was used to locate appropriate monitoring sites, no further aerial survey have been undertaken since the commencement of the MMTS-1.

3.4.3 Establishment and Operation of the MMTS-1: Environmental Working Group

A requirement of the EMP and RoD for this project was the formation of an Environmental Working Group (EWG) comprising of representatives of interested and affected parties and organisations in the catchment. This group was to oversee the impact of the water transfer on the receiving streams and make recommendation on strategies to mediate possible impacts. The responsibilities of the EWG group were to:

1. Direct the monitoring programme and to evaluate the geomorphological monitoring survey findings and implement remedial measures (no guideline or thresholds have been put in place to determine at which stage remedial measure should be implemented);

2. Assess reports compiled by Umgeni Water on the results obtained from the geomorphological monitoring programme, and

3. Instigate additional research and/or mitigation measures, as necessary (Alletson, 2002).

Umgeni Water as the management authority was designated to manage the EWG committee administration, secretariat, water resource management and water service provision of the MMTS-1, and was given the responsibility to report on the findings of the environmental monitoring and report to the EWG (Gillham, 2003).

The group consists of the following organisations and interested groups:

1. DWAF, KwaZulu-Natal Regional Office;

2. Umgeni Water Head Office, who have been designated to undertake the geomorphological monitoring;

3. Riparian landowners, who would be represented by five peer elected members who would attend meetings and report back to the group;

4. Conservation groups, made up of Ezemvelo KZN Wildlife and KZN Department of Agriculture and Environmental Affairs, and

5. Local Municipalities Mpofana (Mooi River) and uMngeni (Hilton/Howick) (Alletson, 2002).

The EWG met on the 19th August 2002 and again on the 31st March 2003 and has not met since then.

3.4.4 Institution Arrangements and Management of the MMTS-1

The institutional arrangements for the management of MMTS-1 were:

1. Umgeni Water was tasked with the day-to-day management, whose role was to manage and maintain the MMTS-1 infrastructure and to implement the environmental monitoring programme for the receiving streams; whereas

2. DWAF’s role was to manage the transfer logistics and environmental issues.

Roles of both institutions were not clearly defined and the draft “Management Agreement” between DWAF and Umgeni Water remained unsigned. DWAF continued ad hoc environmental rehabilitation activities by dealing directly with key stakeholders, namely affected landowner’s, municipalities and environmental agencies concerning any issues raised. Umgeni Water’s responsibility remained the monitoring of the receiving streams and managing the technical aspects of the MMTS-1 namely the dam, pumpstation and the outfall site. EWG ceased to function.

The short falls of the institutional arrangements and management are:

1. Umgeni Water underwent a management restructure programme during the period under review and that no one was assigned the responsibility of the implement the requirements of the MMTS-1 EMP;

2. DWAF usurped the roles of EWG and Umgeni Water by dealing directly with the various stakeholders when implementing environmental mitigation and remediation;

3. DWAF indicated that a period of 5 years should elapse to allow the receiving stream to reach a state of equilibrium before implementing environmental mitigation measures; and

4. DEAT has the power to follow-up on whether the conditions of the RoD are being met by the applicant, DWAF. However the author could find no evidence that this was being done.

Alletson (2002) proposed in the EMP that a Catchment Management Forum (CMF) would be formed to provide a lobby that would ensure the implementation of this MMTS-1 EMP requirement. The CMF is a DWAF initiative and involves the creation of a forum in which all stakeholders may participate, and would fall under the over-arching Catchment Management Agency (CMA). The development of the CMA for this water management area (Mvoti River to Mzimkhulu River) is still in progress.

In conclusion, one can argue that this is yet another example where South Africa has provided the policy and framework for water resource management but the institutional capacity and co-ordination, and will, are lacking to carry out the good intentions of the policy to fruition.

4. RESULTS AND DISCUSSION

The geomorphological monitoring from the MMTS-1 for the period 23/02/2003 to 30/05/2006, which consisted of the erosion pin data, stream cross-sections and fix-pointed photography, is described and assessed below in relation to the norms and standards given in Section 2.3.

The geomorphological monitoring programme for the MMTS-1 was outlined in Section 3.3. Twenty-one erosion sites were identified and the erosion pins were set in place on the 23/02/2003 (refer to Figure 4.1). The survey sites were divided into three different categories and are outlined in section 3.3.2. Four erosion pin surveys were undertaken after each interbasin transfer had been terminated. For convenience these have been labelled 1 to 4.

4.1 Erosion Pin Surveys

In the initial survey, the erosion pins were hammered horizontally into the stream bank or, in the case of the deposition pins, hammered vertically into the areas in which deposition was seen to occur and the length of the pin exposed was measured and documented. This data became the baseline for subsequent evaluations. In subsequent surveys, the erosion pins were measured, and the change in length indicated whether erosion, which was given a negative value, or deposition, which was given a positive value, had occurred, and the results documented.

In analysing the change in erosion pin length data, lost pins were given null value, as there was uncertainty as to why the pins had been lost. Possible causes for the loss of erosion pins include:

- Water action rotating the pin on its axis causing excessive erosion at the base of the pin, (creating a cone shaped hole) and increasing erosion (Thorne, 1981; Harrelson *et al*., 1994 and Couper *et al*., 2002 in Bartley *et al.* 2006);

- The pin could not be located during the survey due to vegetation covering the site, and

- Animal or human interference (Thorne, 1981 and Harrelson *et al*., 1994).

The issue was raised on how to quantify the erosion that had occurred at the base of the pin. The difference in pin length varied as pin lengths were measured on either side of the pin. The pin itself was seen to either retain the bank soil thus inhibiting the loss of soil, or increase soil loss, this depending on the composition of bank soil type (Thorne, 1981). It was therefore difficult to determine which length should be considered to be representative of the erosion that had occurred at that point, as shown in Figure 4.1. The method described in the report Implementation of Geomorphological Monitoring by Wadeson (2003) was to measure different lengths at each side of the pin, then average these lengths. The procedure of averaging the length of change was not implemented throughout the review period, as the method in the report by Wadeson (2003) was not communicated to the technicians during the review period.

Figure 4.1 Erosion site M2 showing the difference in localised erosion on either side of the bank erosion pin.

4.1.1 Results

The results of the four erosion pin surveys are tabulated in Tables 4.1, 4.2, and Appendix 1, which gives all the data collected during this review period.

Table 4.1 Summary of sites of erosion and deposition for the period under review

Survey No.	Erosion at Sites	Deposition at Sites*	Total No. of Erosion Pins	Total No. of Deposition Pins	No of Erosion pins lost/ survey	No of Deposition pins lost/ survey
1 Period: 10/04/2003 – 10/06/2003 Duration: 60 days Survey date: 20/06/2003 Total volume transferred: 41 295 Mℓ	M2, M3, M6, M8, M11, L4, L5, L6 and L7.	M1, M6, M7, M8, L1, L3 and L6.	64	11	2	2
2 Period: 21/11/2003 - 21/05/2004 Duration: 94 days Survey date: 03/06/2004 Total Volume Transferred: 138 990 Mℓ	M1, M2, M3, M6, M 7, M8, M11, L1, L3, L4, L6 and L7.	M6, M7, and L 5.	69	11	4	4
3 Period: 12/10/2004 - 18/05/2005 Duration: 147 days Survey date: 08/11/2005 Total volume transferred: 104 280 Mℓ	M1, M2, M3, M 7, M8, M11, L1, L3, L4, L5, L6 and L7.	M 6.	74	11	17	7
4 Period: 23/12/2005 – 21/03/2006 Duration: 90 days Survey date: 30/05/2006 Total volume transferred: 55 545 Mℓ	M1, M2, M3, M 7, M8, M11, L1, L3, L4, L5, L6 and L7.	M3	74	11	9	5

* Only nine of the thirteen erosion pin sites had deposition pins.

Table 4.2 Receiving streams erosion monitoring data summary: average lengths of erosion pins and lost pins post transfers, with erosion given a negative value and deposition given a positive value

Pin Site Number	Pin Description	No of Pins/Site	Survey 1 Average change in pin length* cm)	Survey 2 Average change in pin length*(cm)	Survey 3 Average change in pin length*(cm)	Survey 4 Average change in pin length*(cm)	Accumulated change in pin length** (cm)
M1 Reference site	Erosion pins	4	4.1	-5	-1.5	-4	-6.4
	Deposition pin	1	3.6	1 Pin lost	1 Pin lost	1 Pin lost	
M2	Erosion pins	5 + 5***	-1.1	-10.7	-3.9 (3 Pins lost)	-3.5	-19.2
	Deposition pin	1	1 Pin lost	-5.5	-49.1	1 Pin lost	
M3	Erosion pins	4 + 5***	-3.5	-14.6 (1 Pin lost)	-7.9 (1 Pin lost)	11.3	-14.8
	Deposition pins	2	-1.15	-26.8	2 Pins Lost	-11.9	-39.9
M6	Erosion pins	5	-4.3	-11.6 (2 Pins lost)	-6.5 (2 Pins lost)	-3.2	-25.6
	Deposition pin	1	10.0	1.7	14.1	-0.6	25.2
M7	Erosion pins	5	2.9	-1.6 (1 Pin lost)	-11.2 (1 Pin lost)	-6.9	-16.8
	Deposition pin	1	8.5	1 Pin lost	1 Pin lost	15.1	
M8	Erosion pins	4	-0.1	-0.2	-0.8	-8.5	-9.6
	Deposition pins	2	0.8 (1 Pin lost)	-0.75	-0.1	-17.4	-17.6
M11	Erosion pins	4	-6.2	-2.5	All pins lost	All pins lost	-8.7
	Deposition pin	1	-0.6	-12.6	1 Pin lost	1 Pin lost	-13.2
L1 (Reference site)	Erosion pins	5	2 (1 Pin lost)	-3.3	-1.1 (1 Pin lost)	-2.6 (2 Pins lost)	-5
L3	Erosion pins	6	0.3	-13.1	-14.6 (4 Pins lost)	-20.9 (3 Pins lost)	-48.3
L4	Erosion pins	4	-0.03 (1 Pin lost)	-14.2	-5.4	-9.3	-28.8
	Deposition pin	1	-17.5	1 Pin lost	1 Pin lost	1 Pin lost	-17.5
L5	Erosion pins	5	-6	3.7	-2	-1.4	-5.7
L6	Erosion pins	5	-0.8	-6.7	-6.8 (1 Pin lost)	-0.1	-14.6
	Deposition pin	1	3.5	1 Pin lost	1 Pin lost	1 Pin lost	
L7	Erosion pins	8	-3.6	-3.3	-3	-3.7	-13.6

* Average change in pin length is derived by the average sum of the difference in pin length per site, e.g. average change in pin length at M2 at Survey 1 = the average of 0.5, -2.6, -4.4, +1.1, and 0 = -1.1 cm (refer to the figures in Appendix 1).

** The accumulated average change in pin length is derived by the addition of result of the Surveys to determine the amount of soil lost during the period under review i.e. the result at M2 is the sum of -1.1, -10.7, -3.9 and -3.5 = -19.2 (refer to Figure 4.1).

*** Additional erosion pins were placed at site, as the original location was deemed to be out of the mainstream flow.

After the first transfer period, four erosion pin sites lost pins. At M8 and L1, the Lions River reference site, interference occurred, as a result of the bank slumping due to either animal or human activity. Two other erosion pin sites recorded lost pins, M2 and L4, both due to erosion. At M2, the deposition pin was lost due to erosion, evident by the bank slumping. The following trends were noted:

- Excluding the reference sites, erosion occurred throughout the receiving streams and deposition was recorded at six of the nine sites at which deposition pins were placed (Table 4.2). This indicates that the stream under transfer conditions is not in a state of equilibrium (refer Section 2.1.1).

- Due to the interference at Lions River reference site (L1) as mentioned above, it was difficult to compare the reference erosion pin data with the downstream erosion pin data (Table 4.2).

Five additional erosion pins were added to M2, as the existing erosion pin site was seen to be located out of the main flow during the transfer.

The second transfer, which was longer than the first, had an increased number of pins lost (eight) (Table 4.1). The loss at M1 of deposition pin and bank slumping surrounding the erosion pins was due to animals entering the stream. The impact of the transfer on the Lions River was that no deposition was recorded in this stream, which suggests that the stream was eroding. Additional five erosion pins were added to M3 adjacent to the existing erosion pin site, and this was seen to add value to the site as extensive erosion was occurring adjacent to the existing site. The following trends were noted:

- Erosion was recorded at most sites, and deposition occurred at only one site. (Table 4.2), and

- Interference at the reference site (M1) indicated that any comparison was made with the downstream Mpofana erosion pin sites was compromised.

During the third transfer, which had the longest duration, erosion recorded at the most sites and deposition occurred at only one site (M6) (Table 4. 2). Six of the nine erosion monitoring sites lost deposition pins. The number of erosion pins lost during this period increased from 8 to 17. The loss of all the pins at M11 may have been exacerbated due to the re-construction of a causeway immediately downstream of the site prior to the commencement of this transfer.

The fourth transfer, which had a similar duration to the second transfer, resulted in the loss of a greater number of deposition pins, 14 compared to 8 (Table 4.2). Again, at M11 all pins were lost, and the possible reason for this has been outlined above. Only one site (M7) indicated that deposition occurred, but all other sites indicated that erosion had taken place. Therefore the receiving streams could be considered to be unstable and eroding during transfer (see Section 2.1.1).

In assessing the impact of the transfer on the receiving streams, the following may have contributed to Survey 1 and 2 showing less clear erosion/deposition trends than Survey 3 and 4, that earlier transfers had already altered the stream channel to accommodate higher discharge rate.

In survey 3 and 4, the following trends emerged:

- Erosion was record occurred throughout the receiving stream;

- Very little deposition occurred throughout the receiving streams;

- The number of pins lost per site increased compared with Survey 1 and 2, and

- The continual loss of all pins at Site M11, directly upstream of a constriction in the channel. The causeway restricted the flow within the stream channel forcing it to flow laterally which exacerbated the erosion of the banks.

In line with nationally accepted geomorphological monitoring outlined in Section 2.2, the erosion pin monitoring lacked the following:

- Well-documented onsite observations;
- Platform sketches;
- Erosion pin specific photographs; and
- The re-measuring of the stream cross-section after a pin is lost as mooted by Thorne (1981), which determines whether change has occurred.

With the exception of measurement of flow discharge, the methods generally recommended in national procedures for stream geomorphology monitoring (e.g. stream cross sections) were all included in the MMTS-1 geomorphological monitoring plan of (Wadeson, 2003). However, the following key shortcomings in the monitoring plan were identified:

- Inappropriate application of pins to sites where high levels of erosion were anticipated and inadequate procedures specified to deal with the loss of pins;
- Only one cross-section was measured per geomorphological monitoring site, which was inadequate to determine the rate of change; and
- Only one benchmark at which fixed point photographs were taken was allocated to per monitoring site, which was inadequate as only one side of the stream was recorded.

In addition, the application of these methods was not sufficient due to the following.

- The lack of training and understanding of geomorphological monitoring by the technician;

- Inconsistencies in the measurement, re-siting and re-setting of erosion pins;

- There was no procedure in place to determine the magnitude of change when a pin or pins were lost, with reference to the deposition pins and if all pins were lost, gaps in the data resulted; and

- The pins have inherent limitations in that they are a specific length and are hammered into the side of a stream bank. These may or may not be placed in the correct site in relationship to the stream flow path and could inhibit or enhance erosion at the pin site;

- No sketches or diagrams of the geomorphological monitoring sites were drawn; and

- No comparison of aerial photographs could be made due to the differing scales used, the first being 1: 6 500 and the second 1: 30 000, the latter being too small to identify changes that have occurred within the receiving stream channel.

The different geomorphological monitoring methods were integrated to a limited extent, i.e. erosion pins and fixed-point photography were monitored together, but the cross-sections were measured and assessed separately. No overall assessment of geomorphological change was undertaken by using the results from the different methods.

4.1.2 Discussion

There were fundamental problems with the geomorphological monitoring programme as outlined in Section 3.4.1, and therefore it is difficult to draw any conclusion. In addition, the focus of this dissertation was a review of this programme and how it was implemented. Nevertheless, the results did yield the following trends:

- In general, erosion occurred along the entire length of the receiving streams, but the data was compromised by the loss in particular of deposition pins, which as outlined made it difficult to draw any conclusions;

- The loss of pins which were given null value (refer to Section 3.3), with reference to the sites at which deposition pins were placed, prevented determining whether erosion or deposition had occurred during the geomorphological monitoring period under review.

- Minimal erosion and deposition occurred at the control sites, even with the interference at the two reference sites. These sites recorded the lowest accumulated average change in pin length compared with all of the other sites. The expectations are that the erosion would decline in the receiving streams. Evidence strongly suggests that the receiving streams were eroding to a greater degree in comparison to the un-impacted reaches of the streams, altering the stream profile and sinuosity. This erosion is exacerbated at sites M2, M3, L3 and L4 (see Table 4. 2) at which site had an increase in erosion of the stream banks.

- Limited deposition occurred along the entire length of the receiving streams. The high number of lost deposition pins per survey suggests that the stream channel is tending to straighten as expected outlined by Freeman and Rowntree, (2005).

- Erosion monitoring sites which are located immediately upstream of a constriction, i.e. a causeway or bridge are eroded to a greater extent than sites located downstream of such constrictions. Causeway/bridges restricted the flow within the stream channel forcing it to flow laterally, which exacerbates the erosion of the banks.

- Generally, the longer the duration of release, the greater the number of erosion pins that were lost, highlighting the possible influence of release duration on the level of stream erosion.

4.1.3 Conclusions

The following were concluded:

- Although a statistical analysis of the data was mooted, the data was limited and was compounded by the number of lost of pins, which created gaps, therefore the data was of limited value, and cannot to analysed statistically to draw any meaningful conclusions about the rate of change in the receiving streams;

- Three of the four procedures assessed in the literature review for this study, and which are also used internationally as outlined in Section 2.2, do not use erosion pins for monitoring erosion associated with transfer schemes. The USDA procedure indicates that erosion pins are seldom used, and are only appropriate where small changes in the bank erosion are anticipated, and do not give a true impression of the rate and magnitude of change in stream channel profile and width (Thorne, 1981 and Harrelson et al., 1994); and

- In the research reported by Freeman and Rowntree (2005) and Rowntree and du Plessis (2006) it is indicated that IBT's impact the receiving streams by straightening and widening the channel, and erosion pins could be considered to be inadequate to monitor the magnitude of changes that are expected to occur when the transfer continues indefinitely. Freeman and Rowntree, (2005) reported that the receiving streams (Skoenmakers River) for Orange-Fish-Sundays Water Supply System Transfer Scheme had widened and deepened by a factor of 5 in comparison with the Volkers River. The Volkers River and Skoenmakers catchments are adjacent and form part of the Fish River basin in the Eastern Cape, South Africa. These two river systems displayed characteristics and flow regime similar to the

> Skoenmakers before it became a receiving river (Freeman and Rowntree 2005, 73).

The receiving streams of the MMTS-1 were being subjected to a significantly increased discharge rate and, given the theory reported in Section 2.1, high levels of erosion were anticipated in sections of the receiving streams. Therefore, given the recommendation of Thorne (1981) and Harrelson (1994) erosion pins are considered to have limited application for this study.

4.2 Stream cross-sections

Stream cross-sections give a single “cut” across the stream and are used to determine the stream channel profile. The MMTS-1 cross-sections are located at eight sites; each of these sites has a single cross section. The initial survey was completed on 12 February 2003 and this data became the baseline for subsequent evaluation. Four subsequent surveys over the period 12/02/2003 to 29/10/2005 are documented in graphic form (see Appendix 2).

Five of the eight stream cross sections indicate similar trends, which was that no marked change in the stream profile was observed, with a typical example shown in Figure 4.2. The two cross-section site graphs, M3 and L7 (Figures 4.3 and 4.4), indicate the extreme cases, the first showing the greatest amount of erosion and the second showing the greatest amount of deposition.

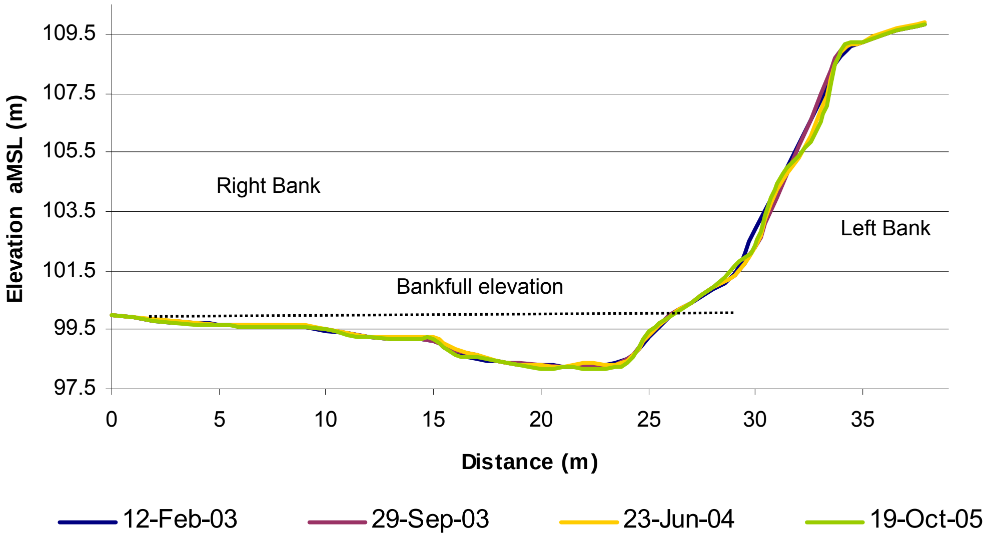


Figure 4.2 Cross-sectional profile at Mpofana Stream M3 site, which is close to the erosion pin site M3, for the period February 2003 to October 2005.

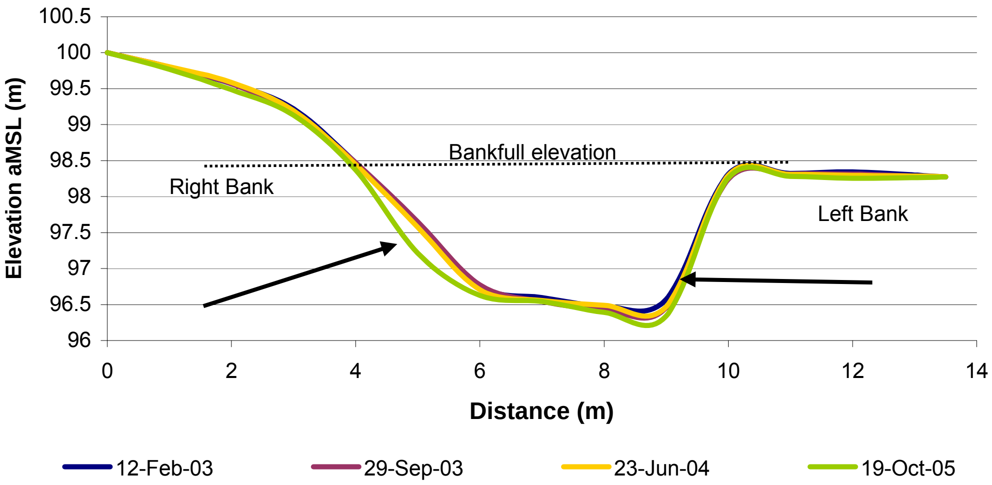


Figure 4.3 Cross-sectional profile at Mpofana Stream M3 site, which is close to the erosion pin site M3, for the period February 2003 to October 2005. (Erosion of the banks is highlighted by the arrows).

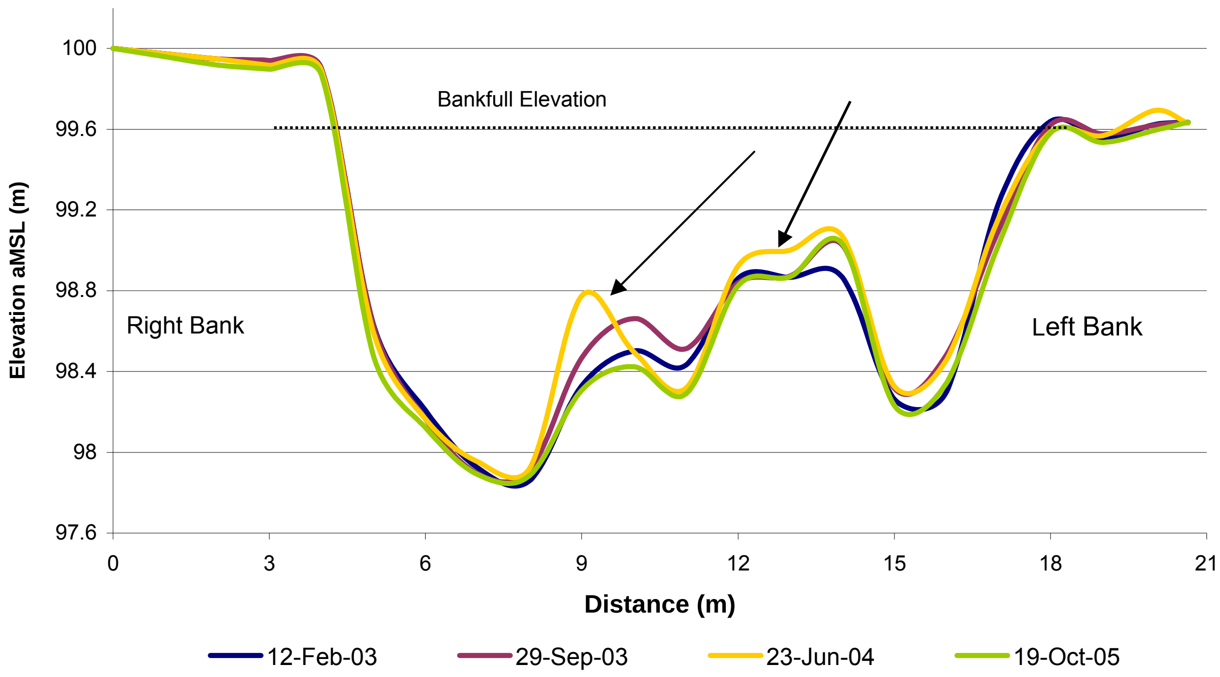


Figure 4.4 Cross-sectional profile at Lions River L7 site, which is close to the erosion pin site L7, for the period February 2003 to October 2005. (The arrows indicate the areas of deposition).

The cross-section graphs indicate that at M3 (Figure 4.3) and L4 (Appendix 2), surveyed between 23/06/2004 and 19/10/2005, the stream had eroded to a greater extent compared to the other sites. A limitation when comparing all Mpofana control site M1 to the other sites on this receiving stream is that only two cross-sectional surveys were undertaken during this study period, as access to the site was restricted.

In cross-section L7, both erosion and deposition occurred. The survey of 23/06/2004 differed from other surveys with deposition occurring at this site (Figure 4.4). As there was no accompanying field notes related to this survey it is difficult to explain this occurrence. The cross-sectional survey of 19/10/2005 shows that much of the sediment deposited at L7 in the 23/06/2004 survey was re-suspended and lost during this subsequent transfer. Although deposition took place within the channel, both the left bank and the right bank eroded slightly over the period monitored.

In this thesis, of the eight sites at which cross-sections were measured, three sites were considered to represent of the changes that had occurred within the stream. Overall, the trends exhibited by these cross sections are:

- Erosion, albeit low levels, was recorded at all cross-sections, particularly at two of the cross sections, and

- Deposition occurred at three of the eight cross-section profiles (refer to Appendix 2).

The limited erosion of the stream bank shown in the results from the cross section surveys compared to the research findings of Freeman and Rowntree (2005) and Rowntree and du Plessis (2003) could indicate that the receiving stream's channel profile may have adapted to the discharge rate due to previous transfers prior to the commencement of MMTS-1 erosion monitoring. The limited duration of the transfer could also possibly influence the magnitude of erosion occurring within the receiving streams as Freeman and Rowntree (2005) and Rowntree and du Plessis (2003) found in their research into the IBT's, and with longer release durations in the future, greater levels of erosion may occur.

The MMTS-1 geomorphological erosion monitoring cross-sections focus on the change in stream channel profile without noting other physical changes i.e. vegetation loss or bankfull level. The MMTS-1 cross-sections have stood alone, as these have not been assessed in conjunction with the erosion pins and fixed-point photography. There has also been no analysis, using aerial photographs, of changes in the planform of the channel.

The USDA, EMAP WSA, IFR and AUSRIVUS procedures use a number of cross-sections per site and each cross-section is "part of a whole" that in conjunction with sketches, fixed-point photographs, ortho-photographs and topographical maps creates a "picture" of the stream channel profile, sinuosity and describes the status or condition of the stream reach. Included in the site assessment are the locations of features outlined in Section 2.2 such as the bankfull level and stream planform. The longitudinal profile determines the slope or gradient of a stream and the changes in width and depth over a prescribed stream length. The geomorphological assessment procedures used a combination of different methods to determine rate and magnitude of change that has occurred in a stream.

Therefore, the use of cross sections in the MMTS-1 geomorphological erosion monitoring is lacking in two important respects: there is an inadequate number of cross sections per site and the cross sections are not complemented adequately by other measures to provide an integrated overall description.

4.3 Fixed-point Photography

The MMTS-1 geomorphological monitoring used fixed-point photography to document change at the erosion pin sites only, and the images were for convenience filed into folders after every visit and these were collated in date order. As yet the photographs have not been assessed to determine magnitude of change or used to identify “areas of concern” as outlined in the MMTS-1 EMP. They have however, added value to the geomorphological monitoring data, (erosion pins and cross-sectional stream profiles) by recording visual changes over time at each site.

This is consistent with the USDA, IFR, AUSRIVAS and EMAP WSA procedures, which recommend that fixed-point photography be used to add value by depicting the physical information collated when making a geomorphological stream assessment, rather than being used as a primary basis for an assessment.

In terms of the project, a typical example of how photographs assist in depicting erosion features in the stream channel can be seen in Figure 4.5.

Pre-Transfer 2003 Mpofana pipeline outfall (M2), Photograph of monitoring pins at the time of site establishment, 23-02-03.

Survey 2003, Mpofana pipeline outfall (M2) post 3.2 m^3/s discharge on the 02-10-03.

M2 Winter Survey 2004 (July)

Summer Survey 2005 (November)

Winter Survey 2006 (June)

Figure 4.5 Historical photographic record of erosion pin site M2 point downstream of outfall.

Although, as the results show, the fixed point photographs provided useful supplementary information to the erosion pins, the following problems in the application of the fixed-point photographs limited their potential value:

1. All erosion pins were not included in the photographs because only a single photographic benchmark was allocated at each erosion pin site, as in the case of M2, M8, M11 and L4 at which deposition pins are placed on the inside bank. As only one stream bank was photographed, the other was left unrecorded.

2. Photographic benchmarks were lost; for example, white painted crosses and marks on trees or fence posts. The marks disappeared over time and the sites changed due to the growth of terrestrial vegetation and change of season. This resulted in pictures being taken at different points from the original benchmarks. Although the use of a Global Positioning System (GPS) was mooted, the handheld instrument available could not identify the exact site of the fixed-point photographic benchmark.

3. The distance between the photographic benchmark on one side of the bank of the stream and the other side, at which the erosion pins were located, resulted in a panoramic view of the erosion pin site but a limited impression on whether change or erosion had occurred, and

4. Only 13 of the 21 monitoring sites, at which photographs were required, were photographed during each survey. The report on the implementation of geomorphological monitoring for the MMTS-1 (Wadeson, 2003) recommended that all 21 monitoring sites required photographs to be taken.

Additional photographs, for example the panoramic photograph (Figure 4.6) indicates several areas where bank slumping has occurred. These photographs gave limited understanding of the changes that occurred and only indicate whether there have been changes in the stream bank’s appearance and a loss of or change in vegetation cover. The photographs were arranged in chronological order to show the changes occurring at each erosion pin site (see Figure 4.6).

These photographs were taken from a distance and did not give a clear indication of the magnitude of bank erosion that had occurred, but gave an indication of the condition of the bank and the loss of vegetation.

Figure 4.6 Image of the Mpofana Stream approximately 30 m downstream of an erosion pin site M3. Arrows indicate where extensive bank collapse has occurred.

Aerial Photography

The MMTS-1 aerial photographs were flown in 1995 at a scale of 1: 6 500 to visually document the state of the receiving streams, identify stream reaches at which erosion could occur and sites at which geomorphological monitoring would be undertaken as part of the environmental impact of the project (Heritage, 1995 and Huggins, *et al*., 2002). However, as indicated in Section 3.4.2, no comparisons can be made, as no further aerial surveys have been flown since the commencement of the MMTS-1.

4.4 An Overall Assessment of the Geomorphological Monitoring implemented for the MMTS-1

With the exception of measurement of flow discharge, the methods generally recommended in national procedures for stream geomorphology assessments (e.g. stream cross sections) were included in the MMTS-1 geomorphological monitoring. However, the application of these methods was generally poor due to the following:

- Inappropriate application of pins to sites where high levels of erosion were anticipated and inconsistencies in the measurement of pins and inadequate procedures to deal with the loss of pins;

- Only one cross-section was measured per geomorphological monitoring site, which was inadequate;

- The fixed point photographs were taken from different points due to the loss of benchmarks and limited to one side of the stream;

- No sketches or diagrams of the geomorphological monitoring sites were drawn, and

- No comparison of aerial photographs could be made due to the differing scales used, the first being 1: 6 500 and the second 1: 30 000, which is too small to identify changes that have occurred within the receiving stream channel.

The different geomorphological monitoring methods were integrated to a limited extent, i.e. erosion pins and fixed-point photography which were monitored together, but the cross-sections were measured and assessed separately. No overall assessment of geomorphological change was undertaken informed by the results from the different methods.

5. RECOMMENDATIONS

In this review the issue raised was whether the geomorphological monitoring programme was appropriate and required to be modified. The indications are that the present geomorphological monitoring of the receiving streams was limited when compared to national procedures reviewed. The challenge is to link the various measurements and observations that comprise the MMTS-1 geomorphological monitoring programme and then conclude from the data and observations, how the flow regimes and stream morphology interact. Therefore sound stream assessment methods should be implemented to determine the rate and magnitude of stream change. Some specific recommendations are given below.

5.1 Geomorphological Monitoring Recommendations

The geomorphological monitoring components have been assessed individually and the results indicate that limited erosion has occurred during this review period. The expectations are that the stream will change from a meandering stream to a straighter, deeper stream with higher sediment loads and widening at points where armouring of the stream bed occurs (Snaddon *et al.*, 1999; Freeman and Rowntree, 2005). Therefore modifications to the geomorphological monitoring procedure should be considered to track the changes that are occurring and these are summarised as follows:

1. The setting out of longitudinal profiles, which would incorporate a number of the present stream cross-sections. The number of longitudinal profiles could be limited to three, spaced one channel width apart, in which stream dimensions, bankfull level, lowest longitudinal profile (described as the lowest water level that a stream will flow), and active channel are determined (Dollar and Rowntree, 2003). These longitudinal profiles should include the identification and measurement of stream slope and sinuosity, location of pond, riffles and rapids, bankfull width and depth, base flow width and depth, floodplain, bank height, stream surface and baseflow watermark. Other physical features that should be indicated and measured are; bars and boulders, riparian vegetation, benches and terraces.

2. Mapping of the planform, which includes sketches of the sites, topographical maps, aerial ortho-corrected photographs and fixed point photography in order to depict and map features of the site that are outlined above in No 1. These methods would allow representative recording of the rate and direction of geomorphological change in the receiving streams and be in accordance with USDA, IFR, WSA and AUSRIVAS procedures.

3. The construction of stream gauging weirs in the Mpofana stream and Lions River upstream of the Mpofana confluence. These sites, and the present weirs located on the Lions River and Umgeni River, should be equipped with real-time telemetry to monitor daily flows. This could be included in the present DWAF initiative of flow monitoring telemetry at selected river-gauging stations which are connected to the Internet. These benefits would be that this monitoring would allow the pump flow rates to be managed in accordance with flow rates within the receiving streams. Further benefits are that:

    - Optimal pumping rates could be implemented and cost of pumping reduced, and

    - Umgeni Water could implement an adaptive flow regime management strategy that could be altered daily to accommodate changes in the flow regime due to storm events and low flows within the receiving streams catchments.

5. Phase 2 of the MMTS requires the volume being increased from 3.8 m^3/s to 4.5 m^3/s, and the transfer will be continuous, with only a short period for maintenance. Thus, erosion pins, due to their limited length and associated problems as outlined by Harrelson *et al*. (1994), may not be an appropriate method of determining the rate and magnitude of change, and whether equilibrium has been reached in the receiving streams. As previously stated, the bank erosion pins determine small rates of change and need to

be surveyed during periods when the transfer is dormant (Thorne, 1981 and Harrelson, 1994).

6. If erosion pins are to be used in the future, then a survey method statement needs to be developed and overseen by an experienced and skilled practitioner. This statement should also give the technicians clear guidelines for the measurement of the pin lengths, and resetting of erosion pins. The technicians could highlight areas of concern at which there has been a greater impact on the stream, rather than just measuring the exposed pin lengths at each site.

5.2 Management Issues of MMTS-1

As previously stated, the roles and responsibilities for management of the MMTS-1 geomorphological monitoring were beyond the scope of this study, but if the geomorphological monitoring of the receiving streams is to be implemented effectively, and be well embedded within an effective decision-making process, then the following need to be implemented.

1. The institutional arrangements within which the monitoring of the receiving streams of the MMTS-1 takes place and the mechanisms through which the roles and responsibilities of the involved parties need to be clearly defined.

2. A management agreement between DWAF and Umgeni Water needs to be signed so that effective environmental management of the scheme could be implemented.

3. The EWG should be firmly established and their role clearly defined. This could be as a forum at which environmental issues could be raised and information disseminated to the riparian land owners.

4. The present geomorphological monitoring for the MMTS-1 needs to be explicitly linked within a management decision-making system. Currently there are no thresholds of change (which trigger particular management

responses) have been identified. Knowledge and understanding of the impact of the MMTS-1 on the receiving streams is limited, and therefore a management system will need to be adaptive. Therefore the monitoring system needs to be set up as an integral component of an adaptive management system, with thresholds explicitly linked to management actions, and

5. A report determining the present status of the receiving stream should be written. This should encompass the present environmental monitoring as well as stream remediation which has been undertaken through the initiatives of DWAF.

5.3 Management of MMTS-1, (Geomorphological Impacts)

The institutional arrangements relating to the management of the MMTS-1 were not explored in this review, and at the time of writing there was no formal management agreement between DWAF and Umgeni Water for management of the MMTS-1. Therefore the responsibility remains within DWAF as the Government authority to monitor and implement remedial action to reduce the impacts of the MMTS-1 and to put in place effective monitoring procedures and the necessary mitigation on the receiving streams prior to the implementation of the MMTS-2.

5.4 Further Research

To improve the environmental monitoring and the management of the interbasin transfers and to allow for adaptive management to be implemented, the following future research is recommended:

- To investigate the institutional environment in which the Mooi-Mgeni Transfer Scheme 1 takes place and how the effectiveness and accountability of institutional arrangements can be enhanced;

- To identify, through a well informed and participatory process, thresholds of change within the receiving streams that would trigger specific management responses;

- To investigate the possibility of using the IFR procedure to assess the environmental impacts of the transfer on the receiving stream. As the IFR procedure which was developed in South Africa utilises local expertise, it could be adapted to develop a flow regime that would best suite the MMTS-1 receiving streams, and

- To determine from the IFR procedures the optimal geomorphological monitoring protocols that could be implemented so as to determine the impacts of the transfer on the receiving streams.

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