

EXECUTIVE SUMMARY

INTRODUCTION

Initiatives have been set in place world-wide to develop river classifications that can be used as the basis of determining a reference condition against which resource protection measures can be evaluated (eg. Apfelbeck, 2001; Rosgen, 1998; Environment Canada, 1999). In South Africa, the present ecological state (PES) of a river reach is an expression of the degree of modification from the reference condition (RC), the condition of the river in its natural state. Whilst methods have been established for the derivation of PES and reference condition for biological components (e.g. Dallas, 2000; Dallas & Fowler, 2000), there has not, to date, been an established method for the derivation of the geomorphological reference condition or the present geomorphological state (PGS). As the geomorphology of a river channel provides the physical template for river ecosystems, the geomorphology is a critical component of the integrated reference condition and the PES of a river.

PROJECT AIMS

The aims, as listed in the project proposal, are as follows:

- to establish a geomorphological database for South African rivers.
- to develop a method to determine the geomorphological reference condition (GRC) for a river reach. This is defined as the channel morphology that would be characteristic of a river reach under natural conditions and would provide habitat to support the natural fauna and flora. It is recognised that this morphology can change in response to the inherent variability of natural systems.
- to develop guidelines for classification of the present geomorphological state (PGS).
- to refine the geomorphological index for the biomonitoring programme.

CHAPTER ONE: INTRODUCTION AND CONTEXT

This chapter provides a general introduction to the project. The project aims are listed and a brief description of the approaches taken is presented.

In terms of the reference condition, the initial approach of this project was to classify river reaches in terms of their zonal gradient classes (see Rowntree *et al.*, 2000) and assess whether channel morphology and dominant bed material could be accurately predicted using channel gradient. If common groupings could be found for undisturbed 'reference' sites, it would then be possible to gauge how far a 'disturbed' reach was removed from its reference condition. If the gradient did not accurately predict the morphology and/or bed material of the reach, it would be assumed that an alteration from reference had occurred. However, while using the data collected at available sites within the RHP, convincing relationships that could be used to define reference condition remained elusive. It was decided that a different approach with more of a systems focus would be taken.

Guidelines for assessing the present geomorphological state were developed in association with a project initiated in 2003/2004 (Project no 2003-046) as a DWAF/RQS study in collaboration with IWR S2S (Thirion & Kleynhans, 2003). The approach to assessing the PES for geomorphology crystallised as a result of collaborative model development. One output from this project has been a series of rule-based models that are collectively known as Assessment Indices. The model for Geomorphology is termed the geomorphology driver assessment index (GAI). The framework for the database is now in place, but data input is an ongoing process.

CHAPTER TWO: CONCEPTUAL BASIS FOR THE GEOMORPHOLOGICAL REFERENCE CONDITION – A REVIEW OF RELEVANT LITERATURE

This chapter reviews literature regarding geomorphological change and the reference condition concept. A brief overview of some of the approaches (both local and international) to the challenge of deriving a reference condition in natural systems is presented.

Internationally, there are two main approaches to deriving ecological reference conditions, namely the multimetric approach and the multivariate approach (Dallas, 2000). If the multimetric approach is selected, sites are classified according to geographic and physical attributes such as climate, physiography, geology, soils and vegetation, as well as additional variables, e.g. stream size, hydrologic regime, elevation and natural riparian vegetation.

Table E.1 Geomorphological Zonation of River Channels (after Rowntree and Wadeson, 1999)

Longitudinal zone	Macro-reach characteristics			Characteristic channel features
	Valley form	Gradient class	Zone class	
<i>A. Zonation associated with a 'normal' profile</i>				
Source zone	V10	not specified	S	Low gradient, upland plateau or upland basin able to store water. Spongy or peaty hydromorphic soils.
Mountain headwater stream	V1, V3	> 0.1	A	A very steep gradient stream dominated by vertical flow over bedrock with waterfalls and plunge pools. Normally first or second order. Reach types include bedrock fall and cascades.
Mountain stream	V1, V3	0.04 - 0.99	B	Steep gradient stream dominated by bedrock and boulders, locally cobble or coarse gravels in pools. Reach types include cascades, bedrock fall, step-pool. Approximate equal distribution of 'vertical' and 'horizontal' flow components.
Transitional	V2, V3, V4, V6	0.02 - 0.039	C	Moderately steep stream dominated by bedrock or boulder. Reach types include plain-bed, pool-rapid or pool riffle. Confined or semi-confined valley floor with limited flood plain development.
Upper Foothills	V4, V6	0.005 - 0.019	D	Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plain-bed, pool-riffle or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow flood plain of sand, gravel or cobble often present.
Lower Foothills	V8, V10	0.001 - 0.005	E	Lower gradient mixed bed alluvial channel with sand and gravel dominating the bed, locally may be bedrock controlled. Reach types typically include pool-riffle or pool-rapid, sand bars common in pools. Pools of significantly greater extent than rapids or riffles. Flood plain often present.
Lowland river	V4, V8, V10	0.0001-0.001	F	Low gradient alluvial fine bed channel, typically regime reach type. May be confined, but fully developed meandering pattern within a distinct flood plain develops in unconfined reaches where there is an increased silt content in bed or banks.
<i>B. Additional zones associated with a rejuvenated profile</i>				
Rejuvenated bedrock fall / cascades	V1, V4	>0.02	A/B/Cr	Moderate to steep gradient, confined channel (gorge) resulting from uplift in the middle to lower reaches of the long profile, limited lateral development of alluvial features, reach types include bedrock fall, cascades and pool-rapid.
Rejuvenated foothills:	V2, V3, V4, V6	0.001 - 0.02	D/Er	Steepened section within middle reaches of the river caused by uplift, often within or downstream of gorge; characteristics similar to foothills (gravel/cobble bed rivers with pool-riffle/ pool-rapid morphology) but of a higher order. A compound channel is often present with an active channel contained within a macro channel activated only during infrequent flood events. A limited flood plain may be present between the active and macro-channel.
Upland flood plain	V8, V10	< 0.005	Fr	An upland low gradient channel, often associated with uplifted plateau areas as occur beneath the eastern escarpment.

Sites are then designated to homogenous zones and it is assumed that test site characteristics should, ideally, match the conditions of the reference sites in that zone (Dallas, 2000). The multivariate approach, by comparison, does not make assumptions regarding the similarities of biological communities at different sites based on either physical or chemical attributes. Instead, sites are classified by multivariate analysis of fauna and then probabilities of sites belonging to each of the groups of reference sites are calculated.

The approach used in South Africa to date (i.e. for biotic components) is a regional, multimetric one whereby homogenous zones are delineated and test site conditions are assessed against reference conditions established for each zone. Initially, it was thought that this would be the approach most suitable for identifying the geomorphological reference condition.

Progress has been made in terms of geomorphological classification and zonation (see Rowntree & Wadson, 1999; Rowntree *et al.*, 2000). It is thus possible to group rivers and river reaches in a regional or longitudinal manner (see table E.1) according to their morphological similarities. By making use of available historical data and empirical data, it was thought that reference sites could be identified, and reference conditions (which, it was thought, would be in the form of ranges) established in terms of form and process.

CHAPTER THREE: AN EMPIRICAL APPROACH TO DETERMINING THE REFERENCE CONDITION FOR SOUTH AFRICAN RIVERS

For the purpose of this chapter, the definition of reference reach that was adopted was “the channel morphology that would be characteristic of a river reach under natural conditions and that would provide habitat to support the natural fauna and flora.”

The following objectives were adopted to arrive at the geomorphological reference conditions for South African river sites:

1. Define what is meant by “reference condition” in terms of geomorphology.
2. Collect data for a wide range of field sites and compile into a geomorphological database.
3. Categorise channel characteristics according to the zone classes proposed by Rowntree *et al.* (2000).
4. Test the hypothesis that reach characteristics can be predicted from the reach drivers gradient and stream power.
5. Assess the effect of human induced disturbance on the above relationships.
6. Make recommendations for determining the reference condition of a river reach.

In this chapter, the methods that were adopted to address each objective are presented with results and discussions.

The chapter concludes that the findings obtained by taking the approach outlined above were not conclusive with respect to reference conditions. However, the data that has been collected has suggested areas that may be worthy of further investigation. It was proposed that a different approach be taken in the endeavour to define and describe geomorphological reference conditions for South African river sites. An alternative approach was suggested. This new approach is presented in the chapters that follow.

CHAPTER FOUR: DEVELOPMENT AND APPLICATION OF THE GEOMORPHOLOGY DRIVER ASSESSMENT INDEX

At the start of the present reference condition project there was no standard set of methods in place to derive the EcoClassification for a river reach. To meet this need a study was initiated in 2003/2004 (Project no 2003-046) as a DWAF/RQS study in collaboration with IWR S2S (Thirion & Kleynhans, 2003). The aim of this project was "to devise a set of rule-based models to determine the present ecological state (PES) for various components and an integrated ecological river state (referred to as the Ecstatus)" (Kleynhans *et al.*, 2005). The rule-based models focussed on developing a reliable and consistent method to determine the ecological categories (ECs) for the present and the future condition of the river reach.

The EC for each component is assessed using a rule-based model; the model output is an assessment index that can be related directly to the ecological category as indicated in Table E.2. The Geomorphology EC is assessed using the Geomorphology Driver Assessment Index (GAI). This chapter describes the process of developing the GAI rule based model.

Figure E.1 provides a framework within which a driver-driven assessment of change can be placed. Aerial photographs or anecdotal evidence can be used to assess historical changes to channel morphology. A field assessment of the present channel will provide evidence of ongoing change in terms for example of bank erosion, bar development, loss or gain of secondary channels. Finally the river zone, classified in terms of reach gradient and stream power, can be used to get a first approximation of expected channel morphology. These four aspects can then be compared to derive an assessment of the change rating.

Table E.2 Generic ecological categories for EcoStatus components
(Kleynhans *et al.*, 2005)

ECOLOGICAL CATEGORY	DESCRIPTION	SCORE (% OF TOTAL)
A	Unmodified, natural.	100
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	80-99
C	Moderately modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.	60-79
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions have occurred.	40-59
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions are extensive.	20-39
F	Critical/Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	0-19

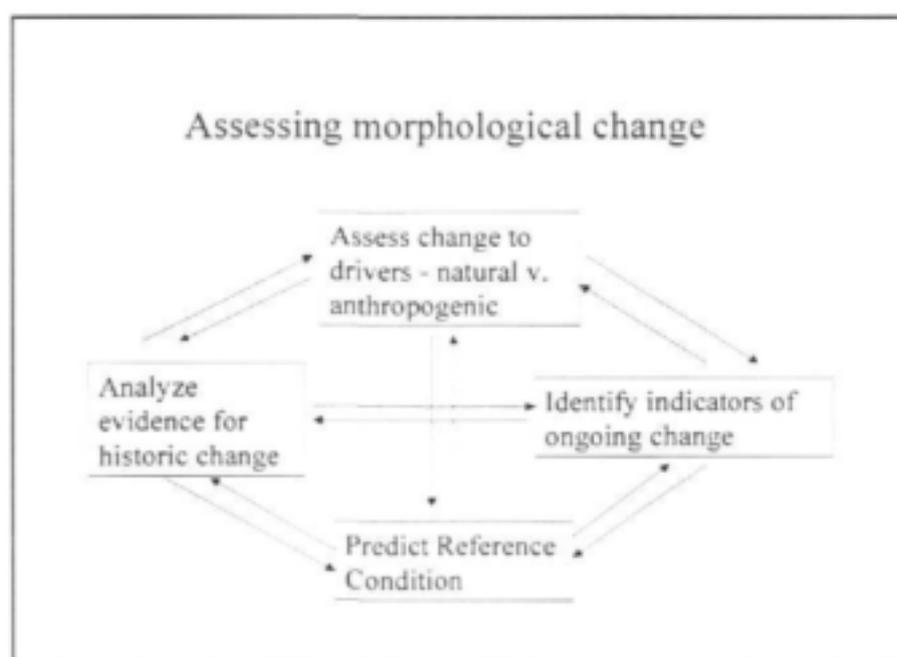


Figure E.1 Framework for assessing morphological change

A fundamental difference between the GAI as presented here and earlier assessment methods is a change to the conceptualisation of the reference condition. Rather than seeing the reference condition as being a deterministic channel morphology that can be predicted from reach and catchment controls, the reference condition is conceptualised as a geomorphological system composed of flows, storages and responses that are dynamic and indeterminate. This thinking is in line with the system paradigm that is being applied increasingly to fluvial geomorphology. This paradigm is explored further in Chapter 5.

CHAPTER FIVE: ADOPTING A SYSTEMS PARADIGM IN FLUVIAL GEOMORPHOLOGY

Despite the long history of the discipline of fluvial geomorphology, cause-effect relationships within river systems are relatively poorly understood, and difficult to unravel. Ways of thinking (dubbed "paradigms" by Kuhn in 1970) in Western science can be broadly broken down into two main classes, namely reductionism and holism (or the "systems approach"). The reductionist approach holds that a complex entity can be understood as a sum of its constituent parts (i.e. if one can fully comprehend each of the parts and its relationship to other parts, one can understand the whole), whilst the holistic approach holds that it is not only impossible to fully understand each part of a system and its relationships with other parts, but that a system can exhibit its own properties independent of the characteristics of its parts, i.e. a system can behave as an entity in its own right (Laszlo, 1972; CALRESCO, 2004).

An holistic outlook is warranted in river science. Rivers are widely recognised as being natural *systems*. A system may be simply defined as "A collection of interacting parts that forms an integrated and consistent whole, isolatable from its surroundings" (CALRESCO, 2005).

In this chapter, certain relevant systems concepts are presented and defined, and the history of systems thinking in fluvial geomorphology is outlined. In addition, the applicability of systems theory concepts to fluvial geomorphology in general is discussed, particularly within the context of this project.

Within the context of this particular project, perhaps the most intriguing systems concept is that of self-organization.

As has been pointed out in Chapter 2 of this report, the original notion of a "reference condition" has been replaced as a systems perspective has been taken. It now seems more important to understand the system that is being dealt with, and to gain some idea of the trajectory that it is on. If systems tend to self-organize after a perturbation, then a measure of a system's type and degree of self-organization would go a long way towards allowing one to gain an understanding of its trajectory, and hence its potential endpoints.

Self-organization, and particularly self-organized criticality, is a systems concept which needs to be further investigated in the context of managing South African river systems. Self-organisation is a measure of the systems intrinsic adaptation to the current set of external drivers. Self-organised criticality implies a hierarchy of pattern and structure that could be considered to be the optimal ecosystem condition given the current externalities. The 'reference condition' may be better thought of as the *attractor* to which the system is tending, rather than a *past* condition from which it has moved. It is proposed that the degree of self-organisation is a better measure of ecosystem health than a measure that compares the present condition to a historic reference condition.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

This chapter reviews the aims of the project and states how each one of these has been addressed. Conclusions that have been reached with regards to each one are presented. Furthermore, the chapter presents the new directions that this project has suggested.

The primary aim of this project was to derive a method by which to gauge the geomorphological reference conditions for South African rivers. If these systems are indeed nonlinear dynamical systems, however, deriving a "reference condition" may be redundant. These systems exhibit chaos and associated unpredictability and although sensitive to initial conditions, these initial conditions become irrelevant to the present condition. It is proposed that the degree of self-organization is a better measure of ecosystem health than a measure that compares the present condition to a historic reference condition and that it would be useful to apply a systems theory framework to understanding and managing trajectories of change in river systems.

Work done abroad has identified self-organization at a variety of scales in geomorphological systems (see Chapter 5). In order to explore this idea further within the South African context, certain research needs can be identified. In this chapter, some of these needs are presented, along with ideas as to how these could be addressed.