RIVER ECOCLASSIFICATION

MANUAL FOR ECOSTATUS DETERMINATION (Version 2)

MODULE B:

Geomorphology Driver Assessment Index (GAI)

Report to the

Water Research Commission

by

KM Rowntree[1]

with contributions from

L Kelly[1] and M Rountree[2]

[1] Department of Geography, Rhodes University, Grahamstown

[2] Fluvius Environmental Consultants, Cape Town

WRC Report No TT 551/13

JULY 2013

Obtainable from:

Water Research Commission
Private Bag X03
Gezina, Pretoria 0031, South Africa

orders@wrc.org.za or download from www.wrc.org.za

The manuals for ecostatus determination emanate from studies which were initiated within the WRC research consultancy, K8/619, titled: "*Designing a Riparian Vegetation Response Assessment Index as part of the existing EcoStatus determination process*".

This report emanates from WRC research consultancy, K8/708, titled: *"Refinement of the Geomorphological Driver Assessment Index and development of training manuals for users"*

This module is the second of a series. Please refer to page iii for a list of the other publications.

ISBN 978-1-4312-0405-2
Printed in the Republic of South Africa

STRUCTURE OF THE MANUAL

The manual consists of the following modules:

- MODULE A: Ecoclassification And Ecostatus Models
  (WRC Report No. 329/08)
- MODULE B: Geomorphological Driver Assessment Index (GAI)
  (This report)
- MODULE C: Physico-Chemical Driver Assessment Index (PAI)
  (Pending)
- MODULE D: Fish Response Assessment Index (FRAI)
  (WRC Reports No. TT 330/08 and TT 331/08)
- MODULE E: Macroinvertebrate Response Assessment Index (MIRAI)
  (WRC Report No. TT 332/08)
- MODULE F: Riparian Vegetation Response Assessment Index (VEGRAI)
  (WRC Report No. TT 333/08)
- MODULE G: Index Of Habitat Integrity
  (WRC Reports TT 377/09 and TT 378/09)

This module is Module B and consists of the GAI manual. The module provides the background to and scientific rationale for GAI. It also provides the explanation of the GAI field sheets, the GAI model as well as all necessary information on the different GAI levels.

PURPOSE OF THE MANUAL: MODULE F

Provide a step by step guideline to the appropriate specialists on how to use the GAI models.

WHO SHOULD APPLY THESE MODELS?

GAI 3: An experienced aquatic ecologist with understanding of the responses of geomorphology to a range of impacts.

GAI 4: An experienced riparian vegetation specialist

NOTE: It is strongly recommended that the user participates in training courses and/or contact the authors of this manual when applying the models

REFERENCES

Rowntree KM. 2013. Module B: Geomorphology Driver Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 551/13.

ACKNOWLEDGEMENTS

All the persons that participated in the development in alphabetical order:

Du Preez, L (Rhodes University)

Glenday, J (University of California)

Joubert, R (Rhodes University)

Rountree, M (Fluvius Environmental Consultants)

Van der Waal, B (Rhodes University)

Wadeson, RA (Private)

EXECUTIVE SUMMARY

1. ECOCLASSIFICATION

EcoClassification – the term used for the Ecological Classification process – refers to the determination and categorisation of the Present Ecological State (PES; health or integrity) of various biophysical attributes of rivers relative the natural or close to the natural reference condition. The purpose of the EcoClassification process is to gain insights and understanding into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. This provides the information needed to derive desirable and attainable future ecological objectives for the river.

The steps followed in the EcoClassification process are as follows:

1. Determine reference conditions for each component.
2. Determine the Present Ecological State for each component as well as for the EcoStatus. The EcoStatus refers to the integration of physical changes by the biota and as reflected by biological responses.
3. Determine the trend (i.e. moving towards or away from the reference condition) for each component as well as for the EcoStatus.
4. Determine causes for the PES and whether these are flow or non-flow related.
5. Determine the Ecological Importance and Sensitivity (EIS) of the biota and habitat.
6. Considering the PES and the EIS, suggest a realistic and practically attainable Recommended Ecological Category (REC) for each component as well as for the EcoStatus.
7. Determine alternative Ecological Categories (ECs) for each component as well as for the EcoStatus for the purposes of providing various scenarios.

The EcoClassification process is an integral part of the Ecological Reserve determination method and of any Environmental Flow Requirement method. Flows and water quality conditions cannot be recommended without information on the predicted resulting state, the Ecological Category.

Biological monitoring for the River Health Programme (RHP) also uses the EcoClassification process to assess biological response data in terms of the severity of biophysical changes. However, the RHP focuses primarily on biological responses as an indicator of ecosystem health, with only a general assessment of the cause-and-effect relationship between the drivers and the biological responses.

2. ECOSTATUS INTRODUCTION

The EcoStatus is defined as

'The totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna and its capacity to provide a variety of goods and services'.

In essence the EcoStatus represents an ecologically integrated state representing the drivers (hydrology, geomorphology, physico-chemical) and responses (fish, aquatic invertebrates and riparian vegetation).

The development of methods to achieve the objectives of this study, focussed on a two-step process -

1. Devising consistent indices for the assessment of the EC of individual biophysical components.
2. Devising a consistent process whereby the EC of individual components can be integrated at various levels to derive the EcoStatus of the river.

The principle followed here is that the biological responses integrate the effect of the modification of the drivers and that this results in an ecological endpoint.

Indices are determined for all the Driver and Response components using a rule-based modelling approach. The modelling approach is based on rating the degree of change from natural on a scale of 0 (no change) to 5 (maximum relative change) for various metrics. Each metric is also weighted in terms of its importance for determining the Ecological Category under natural conditions for the specific river reach that is being dealt with.

3. ECOSTATUS SUITE OF MODELS

The following index models were developed following a Multi Criteria Decision Making Approach (MCDA).

1. Hydrological Driver Assessment Index (HAI)
2. Geomorphology Driver Assessment Index (GAI)
3. Physico-chemical Driver Assessment Index (PAI)
4. Fish Response Assessment Index (FRAI)
5. Macro Invertebrate Response Assessment Index (MIRAI)
6. Riparian Vegetation Response Assessment Index (VEGRAI)

Each of these models result in an Ecological Category expressed in terms of A to F where A represents the close to natural and F a critically modified condition.

4. ECOSTATUS DETERMINATION

The metrics of each driver component are integrated to provide an Ecological Category (EC) for each component. However, the three drivers are not integrated to provide a driver EC. The information required from the drivers refers to the information contained in individual metrics, and which can be used to interpret habitat required by the biota. This information can then be used to determine and interpret biological responses.

The fish and invertebrate response indices are interpreted to determine an Instream Ecological Category using the Instream Response Model. The purpose of this model is to integrate the EC information on the fish and invertebrate responses to provide the instream EC. The basis of this determination is the consideration of the indicator value of the two biological groups to provide information on -

1. Fish: Diversity of species with different requirements for flow, cover, velocity-depth classes and modified physico-chemical conditions of the water column.
2. Invertebrates: Diversity of taxa with different requirements for biotopes, velocity and modified physico-chemical conditions.

Due to time and funding constraints, various levels of Reserve determinations can be undertaken. Each of these relates to an Ecological Water Requirement (EWR) method with an appropriate level of detail and EcoClassification process.

The EcoClassification process, and specifically the detail and effort required for assessing the metrics, varies according to the different levels. The process to determine the EcoStatus also differs on the basis of different levels of information. There are five EcoStatus levels and they are linked to the different levels of Ecological Reserve determination as follows:

1. Desktop Reserve method → Desktop EcoStatus level
2. Rapid I Ecological Reserve method → EcoStatus Level 1
3. Rapid II Ecological Reserve methods → EcoStatus Level 2
4. Rapid III Ecological Reserve methods → EcoStatus Level 3
5. Intermediate and Comprehensive Reserve methods → EcoStatus Level 4.

These five levels of EcoStatus determination are associated with an increase in the level of detail required to execute them. As the EcoStatus levels become less complex, less-complex tools must be used (such as the Index of Habitat Integrity). This set of manuals explains these different tools, how they work and when they should be applied.

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ABBREVIATIONS

DWAF	Department of Water Affairs
EC	Ecological Category
EcoSpecs	Ecological Specifications
EIS	Ecological Importance and Sensitivity
ER	Ecological Reserve
EWR	Ecological Water Requirements
FRAI	Fish Response Assessment Index
GAI	Geomorphology Driver Assessment Index
HAI	Hydrology Driver Assessment Index
IFR	Instream Flow Requirements
IHI	Index of Habitat Integrity
ISP	Internal Strategic Perspective
MCDA	Multi-Criteria Decision Analysis
MIRAI	Macro Invertebrate Response Assessment Index
NAEHMP	National Aquatic Ecosystem Health Programme
PAI	Physico-chemical Driver Assessment Index
PES	Present Ecological State
PES/EIS	Present Ecological State and Ecological Importance and Ecological Sensitivity
RDM	Resource Directed Measures
REC	Recommended Ecological Category
RERM	Rapid Ecological Reserve Methodology
RHP	River Health Programme
RQS	Resource Quality Services
RU	Resource Unit
RVI	Riparian Vegetation Index
SASS	South African Scoring System
VEGRAI	Riparian Vegetation Response Assessment Index

1 INTRODUCTION

According to the National Water Act (Act No 36 of 1998), resource quality objectives for water resource protection include the condition of the instream and riparian habitat. Habitat in turn is largely a result of geomorphological processes that determine the shape of the river channel and the riparian zone, the characteristics of bed material, and the resilience of the channel to change. River geomorphology (or fluvial geomorphology) is therefore an important consideration when assessing river condition, the impact of water resource developments on future river condition and determining resource quality objectives for future water use scenarios.

A river's EcoStatus is based primarily on the biological response (riparian vegetation, fish, invertebrates) to impacts on the river system and is undertaken by means of the EcoStatus model. Biological responses are driven by the condition of the habitat. The GAI is a rule-based model used to assess geomorphic Ecological Category (EC). This Ecological Category can either refer to the Present Ecological State (PES) or to a desired future state related to a particular scenario. Although the Present Ecological State (PES) value (in terms of geomorphology) which is output by GAI is not a direct input into the broader EcoStatus model, the PES values for the biological components (i.e. vegetation, macro-invertebrates and fish) are interpreted in light of the geomorphological PES value.

This chapter describes the principles underlying the Geomorphology Driver Assessment Index (GAI) that is used to assess the Geomorphology Ecological Category and sets out guidelines for using the GAI.

1.1 BACKGROUND

The GAI represents the culmination of many years of work aimed at developing an index of geomorphological condition for river managers in South Africa. The first such index was developed as part of the National River Health Programme (Rowntree and Ziervogel, 1999; Rowntree and Wadeson, 2000). This was a stand-alone index that relied largely on expert judgment to determine the condition of the geomorphology of a river system. Since then, efforts at a national level have been focused on the integration of specialist indices to determine the EcoStatus classification (Kleynhans and Louw, 2008). This necessitated the development of a geomorphological index that is compatible with the format of this approach.

The GAI was developed initially as a component of the Water Research Commission project K5/1306 "Assessment of a Geomorphological Reference Condition – An Application for Resource Directed Measures and the River Health Programme" (Rowntree and Du Preez 2006). The GAI has been developed further through application within a number of Environmental Water Requirement determinations and River Health assessments. These include the Komati River EWR, the Kromme River EWR, the Kat River EWR and the Mzimkulu EWR.

Earlier versions of GAI level III and IV were distributed in 2008. A number of changes have been made to the field forms and spread sheets as indicated in Table 1.1.

Table 1.1 Changes to made to GAI level II and IV 2008 versions

SECTION	CHANGE
Desktop study	Guidelines for a level IV desktop study have been included in Chapter 3.
Classification	The classification section has been extended to include additional features so as to keep a more detailed record of the channel features. Diagrams are included to aid the classification process in the field.
Rating assessment	Extended guidelines have been provided to assist the rating of metrics.
Metrics	The **sediment budget metric** has been changed to a **sediment supply metric**. This takes account of sediment supply from below any major longitudinal disconnectivity. It does account for changes in transport capacity as these will have been accounted for by the longitudinal connectivity metric. For the same reason it does not account for sediment trapped behind an upstream dam.
	The **perimeter resistance metric** has been changed to a **channel stability metric**. This terminology is better understood by the non-specialist. Because it is often difficult to differentiate anthropogenic change from natural change, rating guidelines are given with respect to observable impacts on bank stability (e.g. vegetation clearance).
	The **morphological change metric** has been separated from the three driver metrics. The rating for this metric is used to calculate a separate PES score that can be compared to the PES score calculated from the connectivity, sediment supply and channel stability metrics. This is more logical than combining geomorphological drivers and geomorphological response in one metric. The two PES values are compared and adjustments made to improve the match if justified.
Reference condition	A new section has been included for constructing the reference condition for channel morphology (level IV only)

1.2 INDEX REQUIREMENTS

The following criteria were required to bring the GAI in line with existing EcoStatus assessment tools:

- The index should enable a practical and rapid approach to assess changes in habitat related to geomorphic condition.
- The index is based on the way in which anthropogenic impacts within a river system affect a range of identified system drivers rather than river condition itself. The effect of these impacts need to be expressed as a deviation from the river's natural or "reference" condition. These drivers include:
  - Connectivity (catchment, longitudinal, lateral, vertical)
  - Sediment balance
  - Channel stability

  The assessed change to channel condition is to be used as a check on the assessed driver response.
- The index needs to take into account the dynamic nature of river systems, a consequence being that the reference condition may encompass states in which the river is in disequilibrium with prevailing conditions.
- The index is a rule-based model compatible and consistent with others that have been developed (i.e. HAI, PAI, VEGRAI, FRAI, MIRAI, and the EcoStatus model itself).
- The output of the index spreadsheet is a numerical PES value that can be translated into an impact class ('A'-'F').
- The model has to be able to predict an Ecological Classification (EC) for a range of future flow scenarios.
- The degree of flow-relatedness of the impact class has to be expressed as a percentage.
- The index has to include confidence ratings to ensure that results are interpreted appropriately.

Two levels of the index were proposed in line with Kleynhans *et al.* (2005) and module A of version 2:

- Level 3 for application in the RHP and for rapid Ecological Reserve purposes. This level is aimed at use by generalist aquatic ecologists rather than specialist geomorphologists.

- Level 4 for application in intermediate and comprehensive ecological Reserve determinations. This level is aimed at specialist geomorphologists

- The two different levels of the model need to produce compatible outcomes, although a study undertaken at level IV will allow a more in-depth assessment of geomorphological processes, and will have a higher confidence value than one undertaken at level III.

Figure 1.1 summarises the differences in procedure between a level III and level IV assessment. The main differences between level III and level IV are, firstly, the depth of the desktop study prior to going into the field, secondly, the extent to which the assessor is called upon to make a value judgment based on expert knowledge and thirdly the extent of the study area assessed in the field. Level III assessors are expected to make a limited desktop study to aid site classification whereas level IV assessors are expected to make a more in-depth study to gain insight into geomorphological processes operating in the catchment and study reach. The field assessment for level III is based on readily observable phenomena, or on information readily available from other experts on the team; the level IV assessment requires judgment calls based on an understanding of geomorphic processes. The number of metrics is reduced for a level III assessment. The level III assessor is not expected to construct a geomorphic reference condition based on channel morphology. For a level III assessment the study area is limited to the vicinity of the EWR or biomonitoring site whereas the level IV assessor is expected to make a wider evaluation of the longer reach. Information gathered for a level III assessment should be sufficient for a desktop Reserve study and for documenting changes to channel condition through a biomonitoring programme.

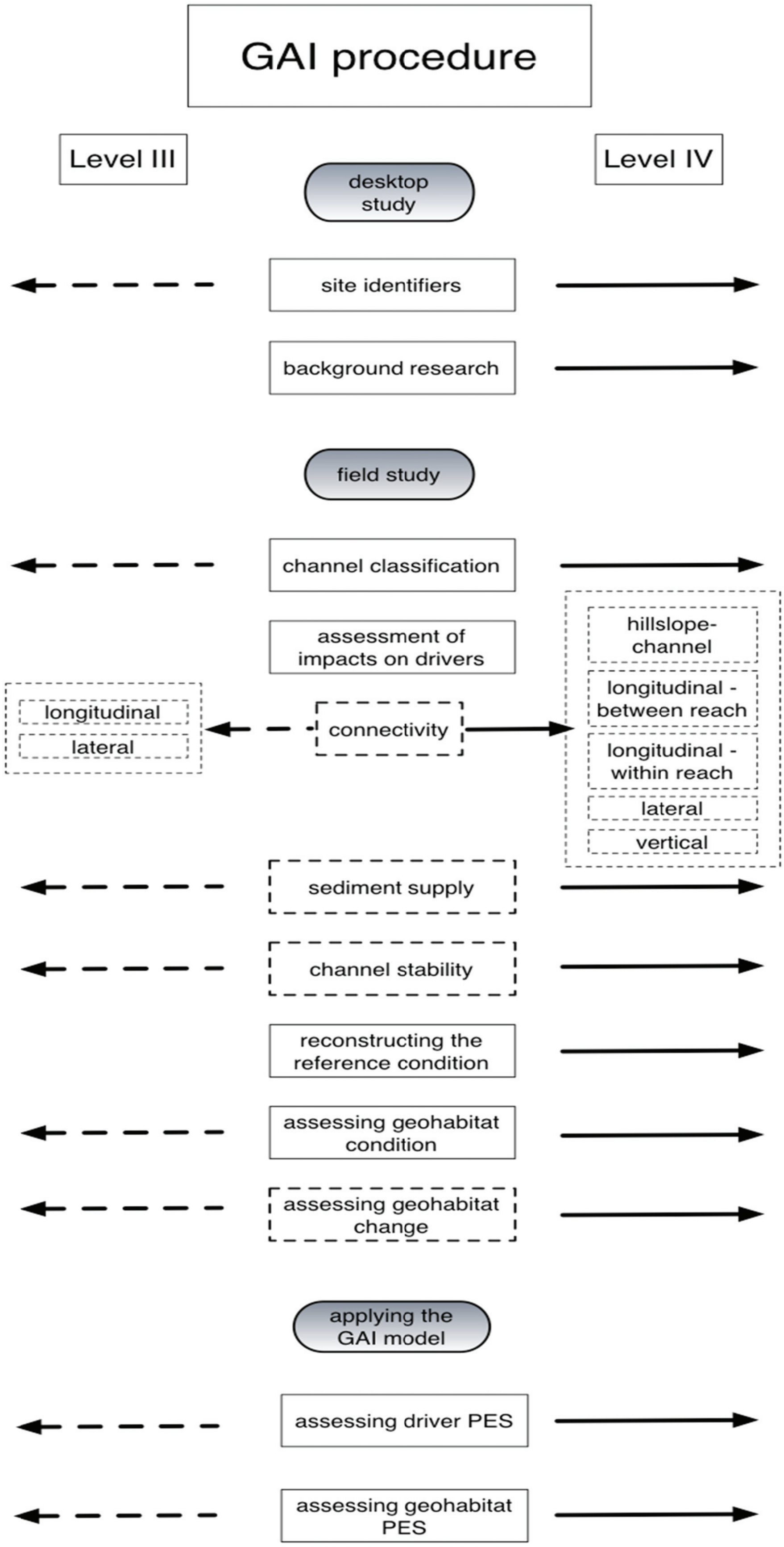

Figure 1.1 The procedure for using GAI for level II and level IV assessments

1.3 GEOMORPHOLOGY AND HABITAT

The purpose of the GAI assessment is to evaluate and interpret the observed changes (at a site or within a study reach) to channel condition caused by anthropogenic impacts that have caused a shift from a derived reference condition. It is important to keep in mind that morphological changes must translate into changes to the instream and riparian habitat.

Habitat can be described in terms of a number of different variables or categories of variables. For aquatic habitats these include flow hydraulics, substrate conditions, and physic-chemical conditions. For riparian habitats these include water availability, frequency of inundation, available rooting depth and soil nutrients. Channel morphology and channel sediments have a direct bearing on flow hydraulics and channel bed substrates (instream) and frequency of inundation and available rooting depth (riparian). These geomorphologically determined habitat characteristics are termed geo-habitats in this report.

When assessing impacts the geomorphologist should work with the ecological specialists to identify important geo-habitat types. Habitat categories identified by the different ecological specialists are given in Table 1.1.

Table 1.2 Geo-habitat requirements of vegetation, fish and macro-invertebrates

Vegetation		**Fish**	**Macroinvertebrates**
River bank zones linked to frequency of inundation		Slow-shallow	Stones out of current
			Sand, fine gravel
		Slow-deep	Silt/mud/clay
	Upper zone	Fast-shallow	Stones in current:
	Lower Zone	Fast-deep	coarse gravel, cobble, boulder
	Marginal Zone	Undercut banks (cover)	Marginal & aquatic vegetation
Instream	Aquatic vegetation	Instream substrate (cover) Marginal and instream vegetation should be included separately	
		Constraints to migration – rock barriers, reduced longitudinal connectivity	

Vegetation zones are closely linked to channel bank features (Figure 1.2). The marginal zone is located at the edge of low water flow so is constantly wetted in a perennial stream. This zone often includes a low depositional bench (termed an inset bench). The lower zone includes the channel bank up to the bankfull height and on to the adjacent flood zone. In a perennial river the bankfull height is achieved approximately once every one to two years. The upper zone extends from the back of the flood zone up the macro-channel bank and on to a terrace, if present, that would be inundated infrequently (less often than once in 3 years).

Geomorphological process that impact on the riparian zone can be erosional or depositional. Bank erosion could remove the present marginal zone and steepen the bank of the lower zone, removing rooted vegetation in the process. Deposition could increase the lateral extent of the marginal zone or create a new lower zone as an inset bench. Accretion on the flood zone could increase the bank height.

The main criteria for specifying fish habitat are the depth and velocity of flow and availability of cover. Depth and velocity are flow discharge dependent, but for any given discharge are modified by the channel structure. Scour of or deposition on the channel bed could result in gain or loss of pools and therefore changes to flow depth. Local variation in velocity depends on the presence of morphological features such as step-pool, pool-riffle or pool-rapid sequences. Stable undercut banks (Figure 1.3) provide cover for fish.

Major channel transformation would be needed to change significantly the velocity-depth-flow discharge relationships but could result from long term restructuring of the channel morphology. The persistence of undercut banks requires stability of the upper bank, which would be lost through processes causing bank failure. Substrate related cover depends on the presence of open cobble or coarse gravel on the channel bed; this would be impaired by the deposition of fines within the open spaces between larger stones (Figure 1.3).

The main distinguishing features for invertebrate habitat are current speed and substrate size, linked to availability of cover providing protection from extreme velocities. There are no specified criteria for depth. The main change in invertebrate habitat that is likely to take place in the short term is a change in substrate due to the erosion or the deposition of fine sediment. Changes to the temporal or spatial distribution of flow velocity (in or out of current) could result from long term restructuring of the channel morphology.

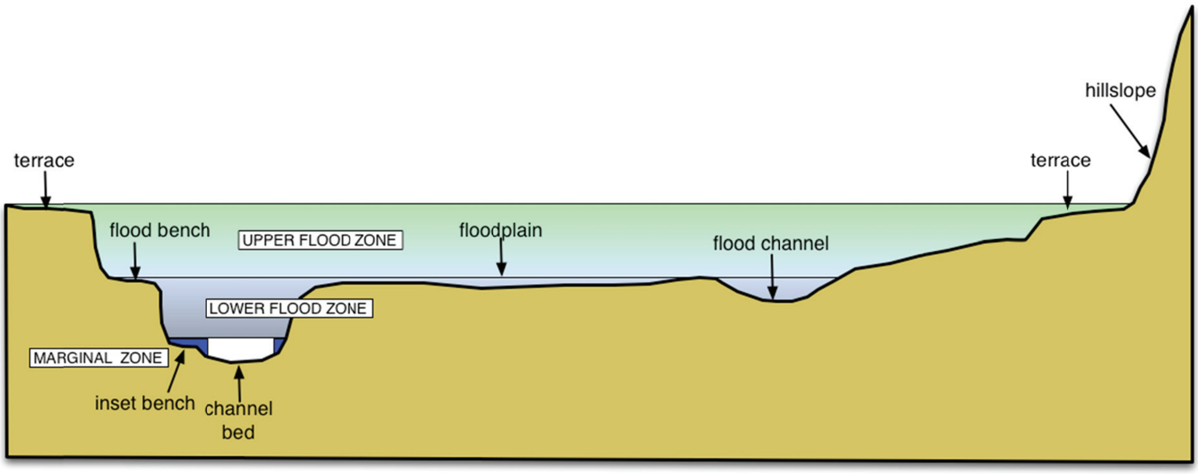

Figure 1.2 Channel cross-section morphology and vegetation zones.

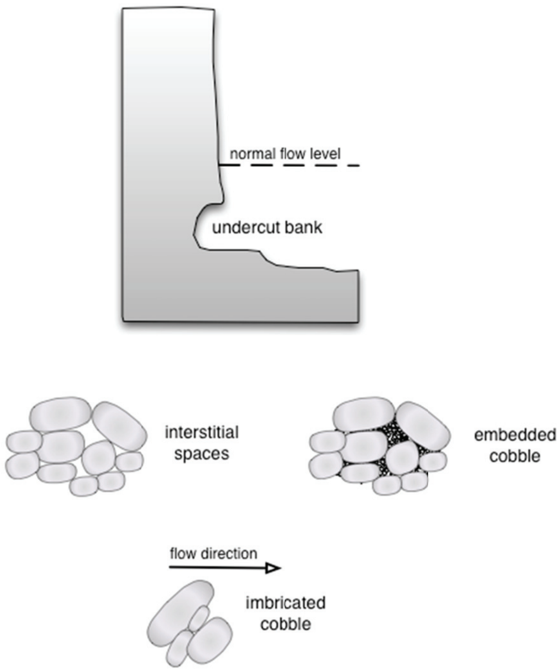

Figure 1.3 Geohabitat providing cover for fish and invertebrates

1.4 FLUVIAL GEOMORPHOLOGY IN PRACTICE

Geomorphology is the science of landform development at space scales ranging from small scale structures on a river bed to whole landscapes and at time scales ranging from minutes to geological era of millions of years. Fluvial geomorphology is the sub discipline of geomorphology that deals with landforms related to processes of erosion and deposition by flowing water. It is therefore the relevant sub-discipline to apply to assessment of river condition.

The main focus of fluvial geomorphology is the river channel, its associated riparian zone and the catchment that generates the runoff, sediment and other materials transported by the river. Fluvial geomorphology therefore deals with a complex interactive system that is hard to describe in terms of simple deductive processes. Although driven by physical laws, the complexity of the fluvial system requires the geomorphologist to acquire a deep understanding of landscape processes and resulting form through experience and, most importantly, field work in a wide range of river systems (Lord et al., 2009).

It is strongly recommended that level IV assessment is made by a person who at least holds a graduate degree that has had a strong component of fluvial geomorphology and, preferably, a postgraduate training that has included a significant field work component backed up by exposure to and application of geomorphic theory.

There is a wide range of texts that provide support to the practical application of geomorphology. An excellent example is the book by Gordon et al. (2004) who write specifically for ecologists. Rosgen (1996) developed one of the earliest classification systems to guide river management in the USA. Sear et al. (2003), Kondolf et al. (2003) and Lord et al. (2009) provide useful background to fluvial dynamics and landscape processes as a starting point for geomorphological studies. Sear et al's (2003) book is available on line from DEFRA, UK. Rowntree (2012) provides an overview of the fluvial geomorphology of southern Africa. She discusses a number of concepts relevant to GAI, using local case studies.

2 DESCRIPTION OF GAI STRUCTURE

This section describes the structure of the Geomorphological Driver Assessment Index (GAI). Although the primary output of GAI is a measure of the Present Ecological State (PES) or Ecological Category (EC), the process and data collection are valuable in themselves and, over time, will help to build a database of river type and condition in South Africa. GAI is designed for qualitative assessment of the response of geomorphological driver impacts in such a way that qualitative ratings translate into quantitative and defensible results. Results are defensible because their generation can be traced through an outlined process (a suite of rules that convert assessor estimates into ratings and convert multiple ratings into an EC).

2.1 GAI MODEL

GAI consists of a spreadsheet model that is composed of a series of metric groups and metrics (described in 2.4 and illustrated in Fig 2.1), each of which is rated in the field with the guidance of data collection sheets (referred to as field forms).

The model for both level III and level IV GAI has three sections, namely a classification section, a condition assessment section and a site suitability assessment. Classification determines the channel type; this in turn guides the relative weightings of the different drivers and metrics. The condition assessment section is used directly to assess the PES and generate the ecological category of a study site. The site suitability section is used to assess the representivity of a selected site in relation to the broader reach in which it is situated. The classification section and site suitability assessments are the same for both levels of the model, whilst the condition assessment section for the two levels is different.

According to Kleynhans and Louw (2008), metrics are individual attributes of each assessment index such as GAI that are rated in terms of their deviation from the expected natural reference condition. “Metrics define what is to be measured” (Kleynhans and Louw, 2008 A2-7). These individual metrics are grouped into metric groups that describe a subset of processes or attributes. Metric groups are ranked and weighted according to their relative importance in determining changes to habitat conditions. Similarly, within each metric group, the individual metrics are also ranked and weighted. This rating and weighting process forms the basis of a Multi Criteria Decision Support Analysis approach (MCDA) that is employed within all components of the Ecostatus model.

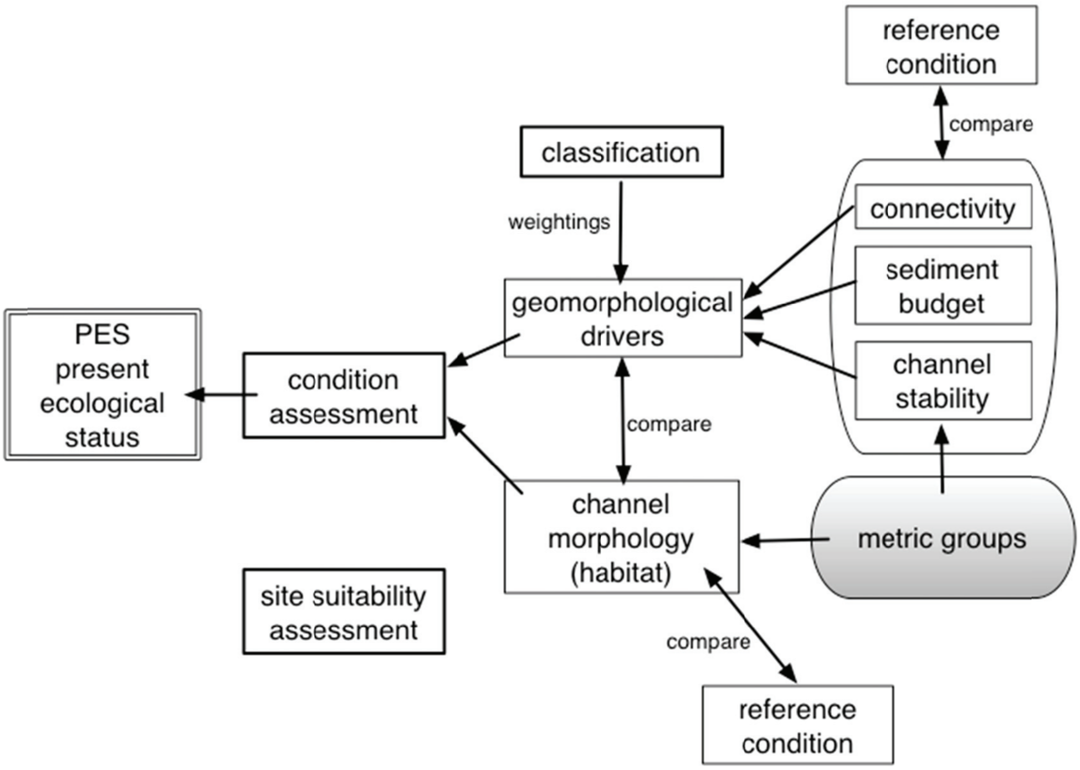

Figure 2.1 Structure of the GAI model

Geomorphological assessment is made for particular "sites", such as a EWR site or a River Health monitoring site. Ideally, the assessment should occur over the entire reach in which the study site (whose co-ordinates are listed as the overall "site" co-ordinates) is located. However, the assessment of an entire reach is often not feasible due to time and/or accessibility constraints.

The recent availability of high quality aerial imagery from Google Earth and from National Geo-spatial Information, South Africa (NGI) (Available: http://www.ngi.gov.za/) has greatly enhanced our ability to extend the assessment to the reach, as well as make more informed judgments about geomorphological processes at the catchment scale. It is recommended that a desktop study (Chapter 3) is carried out prior to the field assessment

Standardized field forms designed specifically for levels III and IV of the index are used to guide and record the collection of data required to complete the GAI for each site. Data are acquired both on a desktop basis and in the field. Once the information required for the completion of the GAI has been gathered, it is entered into the spreadsheets of the GAI model and the PES value and ecological category are generated for the study site. The desktop forms and the field forms for the two levels of the GAI are included as Appendix 1 to 2 of this report.

2.2 CHANNEL CLASSIFICATION

Channel classification is carried out according to five components – valley floor confinement, channel slope, channel pattern, channel type, and morphological unit based on the guidelines presented by Wadeson and Rowntree (1999).

- Valley floor confinement describes the relationship between the valley floor and adjacent hillslopes, ranging from V-shaped valleys in which the river fills the full width of the valley floor to a wide floodplain in which the river is free to migrate laterally. Confinement is therefore a measure of the constraints on lateral movement of the channel; it is also a measure of the degree of coupling between the hill slope and channel and therefore of system connectivity.

- Channel slope, defined as the change in height over distance, is an important determinant of available energy to perform geomorphic work. Together with valley floor confinement, channel slope is a good predictor of possible channel styles for a given discharge regime. Channel slope and valley floor confinement can be used to determine the boundary of river reaches, lengths of a river that are relatively homogenous in terms of their channel pattern and channel type.

- Channel pattern relates to the configuration of the channel or channels in the plan view. It relates to the number of channels (single-thread or multiple- thread), their sinuosity and arrangement. Sinuous channels show clear meanders within the valley floor sediments whilst straight channels follow the line of the valley floor. Note that the valley floor itself may be sinuous, but the channel may be considered straight.

- Channel type is classified according to channel perimeter materials. Channels formed predominantly in bedrock (bedrock channels) are separated from those formed in alluvial sediments (alluvial channels). Mixed channels include alternating sections of bedrock and alluvium. This channel type is common in South Africa. Channel type is then classified according to the dominant bed material (normally the largest ‘common’ size class). The morphology of different channel types (reach type) is then described in terms of suites of characteristic morphological units.

- The channel banks are described in terms of their dominant sediment size and slope gradient. Sediment size determines the cohesiveness and stability of the banks. Sand and gravel are the least cohesive whereas silt and clay have greater cohesion. A mixture of particle sizes adds strength through increased inter-particle friction. Bedrock has the greatest cohesion, but this is reduced by weathering and joint formation.

- Morphological units are in-channel and bank features that provide the physical habitat for aquatic and riparian organisms. They may be erosion or depositional features such as pools or bars respectively.

2.3 REFERENCE CONDITION

Kleynhans and Louw (2008, A1-4) state that “the reference condition describes the condition of the site, river reach or delineation prior to anthropogenic change.” This follows the definition of reference condition by the European Framework Directive (European Commission, 2000) who state that the reference condition should “reflect totally or nearly undisturbed conditions for hydromorphological elements…” Kleynhans and Louw, 2008, A1-4). This definition immediately begs the question of time scale. What is natural? How far back do we need to go to find the reference condition? What about short term change in response to natural drivers? These problems are discussed further by Wohl and Merrits (2007) and Newson and Large (2006).

In a dynamic geomorphological system it is often difficult to separate the effects of anthropogenic disturbance from those of natural disturbances due for example to extreme flood events or intrinsic geomorphic change. South Africa has a highly variable flow regime and channel form may be in disequilibrium with prevailing conditions. A good example is provided by Heritage *et al.* (2004) who studied channel change in the rivers of the Kruger Park following the floods of 2000. Sediment was stripped from many alluvial reaches, transforming them temporarily to bedrock reaches. The rate of recovery (through sediment deposition) was related to the frequency at which the morphological features were exposed to flood events, with channel features within the main channel recovering most quickly. Heritage *et al.* (2004) showed erosion and deposition of sediment to be a natural process in response to a natural disturbance.

Channel morphology is thus the dynamic and indeterminate product of the geomorphological system. Experience has shown that it is difficult to predict a stable morphological end product for any given set of system variables. Although it is possible to point to characteristic channel types that occur within certain geomorphological environments, significant variability exists in space and time. Du Preez and Rowntree (2006) proposed a definition of the geomorphological reference condition that recognizes the dynamic nature or river systems: “the geomorphological system that supports the natural ecosystem, where a system is a set of components connected through flows of energy and matter to accomplish a set function” (Du Preez and Rowntree, 2006 p. 43). The reference condition for GAI is therefore conceived as a set of long-term drivers that are temporarily variable and give rise to a dynamic river morphology. The Present Ecological State is derived by assessing change to these drivers based on observed impacts, rather than relying solely on assessing change to channel morphology relative to an elusive reference.

2.4 METRICS AND METRIC GROUPS

“Metrics are systems of parameters or ways of quantitative assessment of a process that is to be measured, along with the processes to carry out such measurement. Metrics define what is to be measured. …. Metrics can be used to track trends and resources. Typically, the metrics tracked are key performance indicators.” (Kleynhans and Louw, 2008: A1-5).

The PES for geomorphology is assessed firstly in terms of metrics that rate changes to the geomorphological system, rather than changes to morphology and habitat *per se*. These include system changes that impact on flows of energy and matter and changes to factors that may affect the system's resistance or resilience to change. These system level changes are then compared to observed (or estimated) changes in channel morphology and associated habitat components. Large discrepancies indicate that the assessment needs to be re-evaluated.

Four metric groups are utilized in GAI. There are three driver groups and one channel morphology group. The driver groups are connectivity, sediment supply and channel stability (determining bed and bank stability). The PES is assessed with respect to how changes in these metric groups have affected the capacity of the geomorphological system to support the natural ecosystem.

2.4.1 Connectivity

Connectivity is a key indicator of geomorphological system health (Kondolf et al. 2006). Connectivity allows the free flow of energy and materials through the system and, as a result, mutual adjustment between system components. Connectivity is counterbalanced by storage sites that allow material to be retained in the system. The PES of a river's geomorphology can therefore be evaluated with respect to both increases and decreases in connectivity.

Connectivity is assessed in terms of five metrics:

- Hillslope-channel connectivity
- Longitudinal (upstream-downstream) connectivity (between-reach and within reach)
- Lateral (channel-floodplain) connectivity
- Vertical connectivity

Connectivity concepts have been adopted by both ecologists and geomorphologists and provide a unifying framework of assessing river condition. The ecologist Ward (1989) introduced the idea of four-dimensional connectivity that acts in the longitudinal, lateral and vertical directions through time (Figure 2.2). Kondolf *et al*. (2006) used three-dimensional connectivity as a framework for ecological river restoration. They argued that hydrological connectivity is the defining feature of all riverine ecosystems and link river degradation to disconnection. While stressing the negative aspects of disconnection, these authors also recognize the negative impacts of artificially increasing connectivity and stress the need to restore the natural connectivity regime. Geomorphologists have taken a wider catchment scale approach that includes the connectivity between hillslopes and the river channel (Harvey, 2002; Fryers *et al.*, 2007). Fryers *et al.* (2007) focus on the importance of disconnectivity in promoting sediment storage within the landscape and therefore reducing sediment movement through the fluvial system.

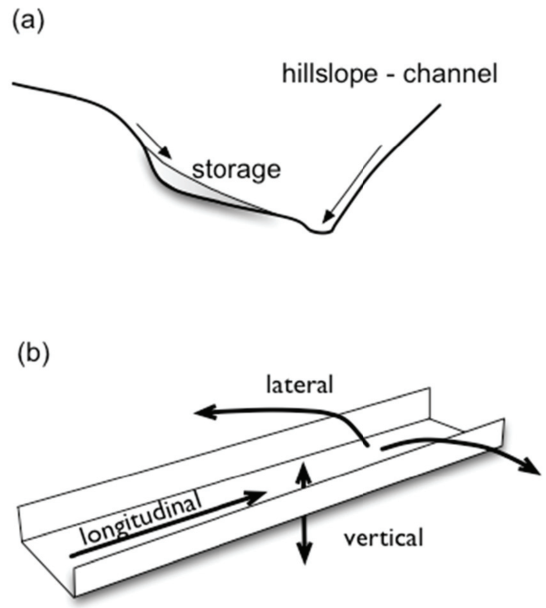

Figure 2.2 (a) hillslope-channel connectivity
(b) longitudinal, lateral and vertical connectivity

Hillslope-channel connectivity, or hillslope-channel coupling, is an important geomorphological system attribute as it determines the ease with which eroded sediment can move from hillslopes to the river channel. It is therefore a measure of sediment delivery. Longitudinal connectivity refers to the down system movement of materials along the main channel network. It can include both the main channel and high order tributaries. Lateral connectivity refers to the movement of materials from the channel outwards onto the banks and floodplain. This is an important process for recharging the riparian zone and redistributing nutrients attached to fine sediments. Vertical connectivity refers to interactions between the channel bed surface and underlying material or hyporheic zone. This may refer to surface water – groundwater interactions or turnover of bed sediment, both important ecosystem processes.

Hillslope-channel connectivity and longitudinal connectivity affect both the magnitude and frequency of flood events, thus changing the capacity for sediment transport, and the supply of sediment itself to downstream reaches. Channel-floodplain connectivity affects the frequency of overbank flows and for sediment storage on flood zones. The connectivity metric group therefore has a direct impact on sediment dynamics in a channel reach.

2.4.2 Sediment supply

The second indicator of geomorphological system change relates to the sediment supply for the specified reach. Channels can be classified as transport-limited or supply-limited. The channel is said to be transport-limited if the supply (including sediment in storage in the reach) is greater than the long-term transport capacity of the flows. The result is a true alluvial channel with a morphology adjusted to the magnitude and frequency of flows (the effective discharge) conveyed through it. If, however, the supply of material within the competence of the effective discharge is less than the transport capacity, the channel is said to be supply-limited. The result will be a bedrock-controlled channel or a channel in which the size of the bed material exceeds the competence of ‘normal’ floods (that is, those floods with a return period of between one and five years). Mixed channels also exist where alluvial and bedrock sections alternate. Whether a channel is supply- or transport-limited will affect its resistance and resilience to change. Bedrock channels are resistant to change but alluvial channels are more resilient as they can modify their channels to achieve a *quasi*-equilibrium with imposed flows.

The primary metrics for sediment supply are divided into hillslope erosion and channel bank erosion. Changes should be assessed in terms of the extent and severity of hillslope or channel bank erosion due for example to land use change, changes to riparian vegetation, or construction of dirt roads; changes related to connectivity that have already been accounted for in that metric group should not be assessed here. The most important changes are those that impact directly on the study reach as the delivery of sediment derived further up the catchment is decreased due to storage.

A third metric is channel mining, which can be responsible for significant losses of sand or gravel from the channel bed.

2.4.3 Channel stability

The third indicator of system change is change to the stability of the channel, that is the resistance of the channel bed, banks and flood zones outside the main channel to erosion. Channel stability is related to the size, cohesiveness of the sedimentary material or extent of bedrock and the effectiveness of the vegetation cover (cf. Rowntree and Dollar, 1996). Normally, anthropogenic disturbance will affect vegetation-related resistance, but in extreme cases where the channel type has changed this could have caused a concomitant change in bank or bed material.

Stability ratings are applied separately to the three metrics channel bed and in-channel bars, channel banks, and the out-of channel flood zone. It is recognized that the optimal ecological condition for the river bed incorporates some degree of mobility, enabling turn over of coarse material, washing out of fines and organic detritus, whereas the optimal condition for river banks and flood zones is one of greater stability. Bars probably fall between these two conditions.

2.4.4 Channel morphology

The last system component is the channel morphology itself. Channel morphology is clearly the direct link to river habitat and in this sense is the most relevant metric group. Changes to channel morphology can be assessed from a comparison of historical aerial photographs, from key field indicators or by comparing the present channel to that expected to conform to the reference condition (see Table 4.11).

Changes to channel morphology over geomorphological time are often difficult to assess for reasons already described. Channels are dynamic features and morphological change is the result of the cumulative effect of a sequence of flood events that erode and deposit sediment. It is therefore difficult to know over what temporal scale to assess morphological change. Change also occurs at a number of different spatial scales ranging from the bed material and bed structure to the channel cross-section (defined in terms of width and depth) to the channel planform (e.g. sinuosity, secondary channels) and the longitudinal pattern (e.g. pool-riffle sequences). Each of these scales is linked to temporal scales of change and change can be considered to be more persistent as the spatial scale increases.

Morphological change is assessed according to two subgroups of metrics: instream and riparian. These are both assessed firstly in terms of habitat changes due to changes in the character, amount and distribution of sediment and secondly in terms of changes in channel geometry that would in turn affect flow hydraulics and hydraulic habitat.

The most significant sediment related changes would be a change in the relative proportion of fines (sand and finer) to coarse (gravel, cobble and boulder). Gravel free of fines often provide suitable areas for fish spawning; if spaces between gravel and cobble are infilled with fine sediment (i.e. the gavels/cobbles become embedded), refugia for macroinvertebrates and small fish are lost (Figure 1.2).

In sand bed channels, silt can be an important fraction inducing stability of channel bars and banks, as well as providing a source of nutrients in the riparian zone. Excessive silt on the channel bed will decrease the natural mobility and infill pores between sand grains, reducing vertical connectivity with the hyporheic zone.

Channel geometry refers to cross-section shape (channel width and depth and the width-depth ratio), the presence and number of secondary channels, and channel roughness. An increase in the width-depth ratio will result in shallower flows, possibly of a lower velocity, for a given discharge, Secondary channels contribute to habitat diversity and provide refuge during flood events. Roughness determines the mean velocity and depth of flows at any given discharge and therefore the pattern of flow types. The main components contributing to roughness are sediment size and bed structure, channel form irregularities and vegetation.

As indicated above, the PES is determined separately for the geomorphic driver metric groups and for channel morphology. By comparing the results, a check is made on the ratings used for assessing the different metrics and adjustments can be made to achieve better conformity. The PES determined from the geomorphic driver metric groups is taken as the final assessment.

If the difference between the PES determined by the geomorphic driver groups and the channel morphology cannot be resolved it may indicate that the channel morphology is in disequilibrium with the current drivers. It is then important to assess the trend that the channel is likely to follow in the future with respect to the reference condition. The trend in the Ecological Category must be provided when assessing environmental water requirements in ecological Reserve studies.

2.5 RATING, RANKING, WEIGHTING

A Multi Criteria Decision Analysis approach is used to quantify the combined effect of the different metrics and, thereafter, to combine the separate components in the Ecostatus model to derive an integrated Ecostatus score. Each metric is rated according to a six-point scoring system. The individual metrics are weighted by their perceived relative contribution to the metric group score; likewise the metric groups are weighted by their relative contribution to the overall GAI PES score.

2.5.1 Rating

Rating of metrics uses the six-point scoring system presented by Kleynhans and Louw (2008) where the driver responses are scored in terms of the degree to which they have changed from the reference condition. The definition of scores is as follows:

0 = No discernible change from reference/close to reference

1 = Small modification from reference

2 = Moderate modification from reference

3 = Large modification from reference

4 = Serious modification from reference

5 = Extreme modification from reference

(Kleynhans and Louw, 2008: A2-8/9)

A more detailed description of ratings for the geomorphological response is given in Table 4.7

Ratings are judged in terms of confidence and the degree of flow relatedness. A confidence value of 5 indicates high confidence based on good data and expert knowledge of the system. A confidence value of 1 would indicate low confidence due to absence of relevant data and limited knowledge about the system. The degree of flow relatedness indicates whether modification from reference is due to changes in flow or to other factors. For example, channel widening could be due to an increased magnitude of annual floods (flow related) or to removal of vegetation for firewood (non-flow related). Flow-relatedness therefore also indicates the extent to which a rating could be altered by managing flows and can be used to guide the application of GAI as a predictive tool in scenario assessment (see Chapter 6).

2.5.2 Ranking and weighting

A weighting system is used to identify those metrics and metric groups (hereafter in this section together referred to as metrics) that are considered to have the most ecological significance in a particular river system. When performing this step in the GAI assessment, rankings and weightings should be made according to the reference reach type (which will have been identified in the classification section) and not according to the condition of the channel at the time of assessment.

Ranks are awarded from 1 (the most important metric) to 4 or 5 (the least important metric) for each section. Ranks are used to award weights to the individual metrics or metric groups. The metric ranked as 1 is awarded a weighting of 100, and the remaining metrics are awarded lower weightings that reflect their relative importance.

The following procedure is used when ascribing ranks (Kleynhans and Louw, 2008: A2-9). For each metric, consider the effect on the geo-habitat if the rating was changed from 0 (no change from reference) to 5 (extreme modification from reference). Which metric would most affect geo-habitat? This metric is rated 1. The second most important metric is rated 2 and so on. Where metrics are considered to be of equal weight, equal ranks can be ascribed. The ranking procedure is used to guide weighting, but plays no further role in calculating weights and weighted scores.

Guidelines for the ranking and weighting of geomorphic drivers are given in section 5.1.

2.6 GAI FORMULATION

2.6.1 Driver metric group impact ratings

The weighted score for each metric group is calculated as follows. A weighted score for each metric is calculated as the product of the rating and weighting. The sum of these weighted scores gives the metric group score.

a) Connectivity

Overall response of connectivity to impact (Ci)

$Ci = (\Sigma(Ci_{1\text{-}n}r \times Ci_{1\text{-}n}w)$

Where

$Ci_{1\text{-}n}r$ = connectivity rating (0-5) for n driver metrics

$Ci_{1\text{-}n}w$ = connectivity weighting for n driver metrics

b) Sediment supply

Overall response of sediment supply to impact (Si)

$Si = (\Sigma(Si_{1\text{-}n}r \times Si_{1\text{-}n}w)$

Where

$Si_{1\text{-}n}r$ = sediment supply rating (0-5) for n driver metrics

$Si_{1\text{-}n}w$ = sediment supply weighting for n driver metrics

c) Channel stability

Overall response of channel stability to impact (CSi)

$CSi = (\Sigma(Ci_{1\text{-}n}r \times Ci_{1\text{-}n}w)$

Where

$CSi_{1\text{-}n}r$ = channel stability rating (0-5) for n driver metrics

$CSi_{1\text{-}n}w$ = channel stability weighting for n driver metrics

d) Morphological change

Overall response of morphological change to impact (Mi)

$Mi = (\Sigma(MIi_{1\text{-}n}r \times MIi_{1\text{-}n}w) + (\Sigma(MRi_{1\text{-}n}r \times MRi_{1\text{-}n}w)$

Where

$MIi_{1\text{-}n}r$ = instream morphology change rating (0-5) for n driver metrics

$MIi_{1\text{-}n}w$ = instream morphology change weighting for n driver metrics

$MRi_{1\text{-}n}r$ = riparian morphology change rating (0-5) for n driver metrics

$MRi_{1\text{-}n}w$ = riparian morphology change weighting for n driver metrics

2.6.2 GAI EC/PES

The Ecological Category (EC) or Present Ecological State (PES) for GAI is calculated as the weighted sum of the three drivers: connectivity, sediment supply and channel stability.

$$EC = PES = \square(Ci \times Cw) + (Si \times Siw) + (CSi \times CSw)$$

Where

Ci = connectivity driver condition

Cw = connectivity driver weight

Si = sediment supply driver condition

Sw = sediment supply driver weight

CSi = channel stability driver condition

CSw = channel stability driver weight

Compare to Mi. If the two values deviate significantly, re-assess and adjust ratings of metrics, starting with those of lowest confidence.

3 PREPARATION FOR GAI APPLICATION – DESKTOP ACTIVITIES

3.1 SITE SELECTION

Study sites should be selected as being broadly representative of the Resource Unit (RU) in which they are situated. In a Reserve study, a geomorphological analysis of river zonation (see Table 3.2) has often been used prior to site selection to identify RU boundaries and possible geomorphic variation within them. Standard practice is to select a study site within the Resource Unit that represents critical conditions in terms of flow variability. Particular attention is normally given to the needs of ecologists and to the site's suitability for hydraulic modelling in the case of an EWR site. Access to the river is also an important consideration so that sites are often located near bridges or another disturbance. The site may therefore not offer the best representation of the geomorphology of the reach in which it is located.

Although the detailed assessment of GAI is undertaken at the site where all other specialists are working, it is important to get as broad an overview as possible of the study reach rather than the study site. Google Earth and modern aerial imagery are invaluable data sources for evaluating river condition at the reach scale. The desktop study therefore provides valuable background information that will aid the GAI assessment.

3.2 DESKTOP STUDY

Processes on the main channel, tributaries or on the catchment slopes are the main drivers of reach and site geomorphology, so it is important as a geomorphologist to have a good understanding of the catchment before going into the field. It is possible to gather important information about the reach/site itself from published literature and databases. Capturing this information forms the basis of the desktop study. The full study should be carried out in support of a Level IV assessment, less detail is required for a Level III assessment .

The desktop study involves a number of separate tasks that can be listed as follows:

1. Capturing site identifiers and characteristics (level III and IV)
2. Describing the reach geomorphology (level III and IV)
3. Preparing a site map (level III and IV)
4. Compiling an inventory of reach and catchment impacts (level IV; recommended for level III subject to available time and required skills)
5. Assessing geomorphological change at the reach and site scale (level IV)

3.3 CAPTURING SITE IDENTIFIERS AND CLASSIFICATION

Table 3.1 is used to record basic information about each GAI site and its reach. This data is captured in section 1 of the field data sheet. The date should only be added at the field site as this refers to the date on which field data was collected.

Some of the required data will have been provided or can be acquired from the project leader. Other data can be captured for topographic maps or hydrological databases as detailed below.

Table 3.1 Site identifiers and classification (extract from field data sheet)

RECORDER		DATE (field data)		
RIVER SYSTEM		MAP REFERENCE		
RIVER NAME		LATUTIDE (S)		
SITE NAME		LONGITUDE (E)		
QUATERNARY CATCHMENT		SITE ALTITUDE (masl)		
CATCHMENT AREA (km^2)		MAR (Mm^3/a)		
FLOW REGIME		perennial	intermittent	ephemeral

An important data source is the 1:50 000 map for the area. The correct map can be identified from the coordinates of the site. For example, if the site/reach coordinates are 29.6789 S, 23.4398 E the map will be numbered 2943 (AA-DD). Additional maps will be required for large catchments if they are to be used to examine upstream features.

The team hydrologist should be able to provide the quaternary catchment number, the catchment area above the site and the mean annual runoff (MAR). Otherwise the quaternary number and MAR can be obtained from the Water Resources of South Africa, 2005 Study by Middleton and Bailey (2008a, 2008b), published by the WRC. Maps are available in GIS format or as hard copy. This set of maps provides a useful resource for getting a general overview of the area of concern. An alternative source is the Atlas of Climatology and Agrohydrology by Schulze (2007).

The flow regime refers to the persistence of water in the river. The hydrologist should be able to help classify the river regime. A perennial river is fed by groundwater that is able sustain the flow through the dry season. A perennial stream only dries up during extreme droughts. An ephemeral river flows during and immediately after rains and is not fed by groundwater. In contrast to a perennial river, an ephemeral river often loses water to a groundwater aquifer below the bed of the channel. An intermittent river is one that fluctuates between being fed by groundwater (effluent), and losing to groundwater (influent), depending on the height of the groundwater table. Periods of effluence and influence may last for several months or years depending on rainfall cycles. A river may also change from effluent to influent along its course depending on geology and valley confinement. Gordon *et al*. (2004) provide further explanation of these flow regime types.

3.4 DESCRIBING THE REACH GEOMORPHOLOGY

The first task is to define the boundaries of the study reach in which the site is situated. This can be done using a combination of Google Earth imagery and the 1: 50,000 topographic map. The reach is then classified according to valley confinement, channel pattern and river zone. The following steps should be followed.

1. Locate the study reach in Google Earth (download from http://www.google.com/earth/index.html) by typing in the coordinates of the reach or the study site (Figure 3.1).

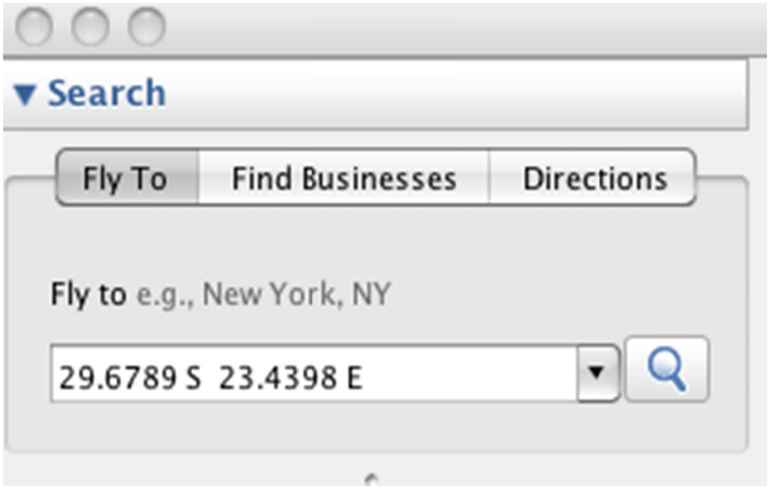

Figure 3.1 Navigating to a location in Google Earth

2. Zoom in to the study reach to investigate the valley form and channel pattern. The boundaries of the reach should be defined by homogeneity in valley form, channel pattern and slope gradient (see below). The channel pattern may vary along the length of the reach, but there should be a recognizable sequence of repeated patterns. For example, a river might switch between braided and single thread pool-rapid.

3. Identify the approximate boundaries of the reach according to the valley form and channel morphology. Redefine the boundaries according to significant changes in channel gradient using the 1:50 000 topographic map. This can be done either by constructing a long profile of the reach from the contours or, with experience, by eyeballing changes in contour spacing along the channel. (If a reach analysis of the entire long profile has already been completed this can be used to identify reach boundaries.)

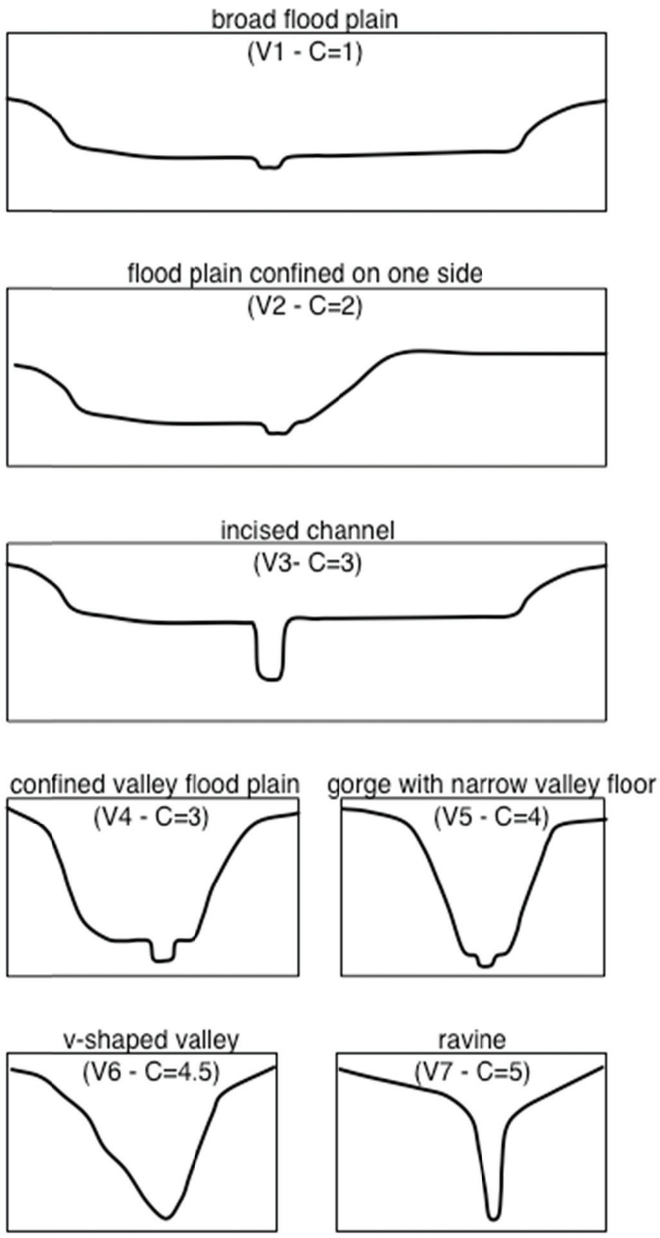

Figure 3.2 Classification of valley confinement

Classify the valley form according to its degree of confinement (Figure 3.2). Valley confinement is a measure of the ability of the channel to shift its position laterally. It is also a measure of the degree of coupling between the hill slope and channel and therefore of system connectivity. Confinement is related to the configuration of the valley floor with respect to the adjacent hill slopes. A rating of 1 is ascribed to the least confined system, which is a wide floodplain. The highest rating is given to a narrow V-shaped ravine in which the channel fills the full width of the valley floor. A channel that is incised into alluvial terraces is given a relatively high rating (3), as the active channel is confined within the macro-channel banks (see Figure 3.2), but potential for hillslope-channel coupling is low. In order to differentiate between incised and non-incised but deep channels, look for evidence of inset flood benches that are equivalent to a floodplain. Low benches with reeds and other marginal vegetation should not be used as indicators of incision.

The presence of alluvial fans may be cause to adjust the valley confinement classification. These are commonly present in confined valley floodplain situations where steep tributaries deposit sediment at the break of slope between tributary and valley floor. In cases where the tributary stream diverges and loses power over the fan surface, the fan forms a hydrological and sediment buffer between the tributary and trunk channel. This buffering effect is lost if the tributary channel incises across the fan and links directly to the main channel. If fans are present increase the channel confinement class by 0.5 and make a note on the field form.

4. Classify channel pattern. Channel pattern relates to the number and alignment of channels and the sinuosity. Five common patterns are recognized: straight, wandering, braided, anastomosing and meandering (see Figure 3.3). Sinuous channels show clear meanders within the valley floor sediments whilst straight channels follow the line of the valley floor. Note that the valley floor itself may be sinuous, but the channel may be considered straight. Anastomosing and braided channels are both multi-thread channels, but anastomosing channels are considered to be more stable and can form in bedrock. Separate stable channels are separated by islands rather than mobile sedimentary bars as is the case in a braided channel.

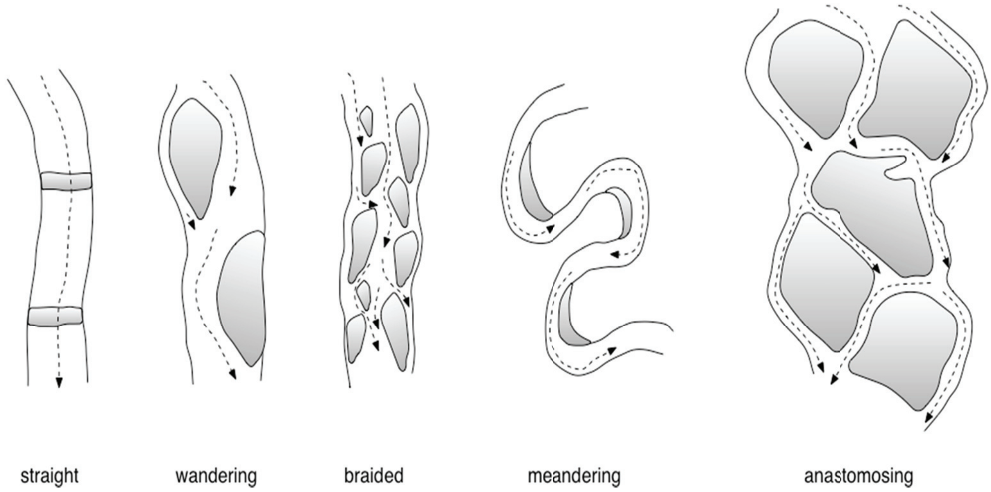

Figure 3.3 Channel pattern classification

5. Calculate the reach gradient. The channel gradient is normally estimated from the contours on a 1: 50 000 map. The distance between the two contours bounding the reach within which the site is located of the site is measured. The gradient is calculated as:

$$\frac{\text{vertical height between contours at either end of reach}}{\text{horizontal distance along length of reach between contours}}$$

Use Table 3.2 to allocate a river zone.

For a level III assessment it is acceptable to use the two contours bounding the site rather than the longer reach. In this case the vertical height will be 20 m.

6. Use Table 3.2 to allocate a river zone.
7. Enter the data in Table 3.3.

Table 3.2 Geomorphological Zonation of River Channels (after Rowntree & Wadeson, 1999) (Further descriptions are given in Table 4.11)

Longitudinal zone	Macro-reach characteristics		
	Valley form	Gradient class	Zone symbol
Source zone	V1	not specified	S
Mountain headwater stream	V6, V7	> 0.1	A
Mountain stream	V6, V7	0.04-0.99	B
Transitional	V4, V6	0.02-0.039	C
Upper Foothills	V4	0.005-0.019	D
Lower Foothills	V4, V2	0.001-0.005	E
Lowland river	V1, V2 V3	0.0001-0.001	F
Rejuvenated bedrock fall / cascades	V5	>0.02	Ar/Br/Cr
Rejuvenated foothills	V4, V5	0.001-0.02	Dr/Er
Upland flood plain	V1, V2, V3	< 0.005	Fr

Table 3.3 Reach characteristics

VALLEY CONFINEMENT	
CHANNEL PATTERN	
REACH LENGTH (km)	
REACH GRADIENT (m/m)	
RIVER ZONE	

3.5 PREPARING A SITE MAP

If the location of the study site is known, zoom into this location in Google Earth to achieve a large-scale map. The length of the channel included on the map should be at least 12 x the channel width so as to include all significant morphological features. Print this out for use in the field. If possible, laminate so that it can be used as the basis of a field sketch.

3.6 COMPILING AN INVENTORY OF UPSTREAM AND CATCHMENT IMPACTS

Topographic maps, aerial photographs and other imagery, and various GIS data bases can be used to identify impacts in the catchment and riparian zone that will affect connectivity, sediment supply and channel stability. Table 3.4 should be used to capture information about impacts. Data should be collected for riparian areas in the reach and for the larger catchment. Note that impacts close to the study reach will have the greatest impact on the channel condition.

3.6.1 Riparian areas

Use topographic maps, Google Earth or other imagery to:

- Describe the riparian vegetation in terms of grass or trees.
- Identify land use or vegetation cover change on the floodplain and channel banks.
- Identify barriers in the channel such as weirs, causeways and bridges.

Note the occurrence and frequency of impacts in Table 3.4.

The assessor should also consult the vegetation specialist and extract information from the Index of Habitat Integrity (IHI) (Kleynhans et al., 2009) if available.

3.6.2 Catchment investigations

Google Earth provides a useful resource for investigating catchment impacts such as upstream dams on main channels, land use change, farm dams, roads and livestock tracks and erosion on hillslopes. Note the occurrence of observed impacts in Table 3.4. In addition, relevant information can be sourced from the IHI (Kleynhans et al, 2009) and the PESESIS (Present Ecological State and Ecological Importance and Ecological Sensitivity – a desk top approach developed for RDM and RQS purposes (Department of Water Affairs, 2009)). The PESISIS outputs are now available for the whole country (Louw, pers.comm. 2013).

If there is a mainstream dam, try to get hold of the information indicated at the bottom of Table 3.4.

Other useful GIS databases that can provide additional information about the river system and its catchment are described below. These are national databases, freely available from the internet or the responsible organization. They provide a good overview, but because they are produced at a national scale they may lose accuracy at the local scale. Expert judgment should be used to assess the local accuracy of the mapped data.

Maps available through the South African Biodiversity Institute (SANBI)

The following digital maps are available through SANBI at http://bgis.SANBI.org

National Land Cover 2009

National scale soil maps (available from AGIS – Agricultural Geo-Referenced Information System, email: agriland@nda.agric.za ; URL: http://www.agis.agric.za/)

National wetlands inventory 2006

Vegetation map of Southern Africa 2006

The National Land Cover 2009 is a set of raster-based maps using a standard 30x30 m grid for the country. It provides up to date information about land cover classified according to:

natural,
cultivation,
degraded,
urban built-up,
water bodies,
plantations,
mines.

Note that the degradation class refers to degraded forest and woodland, degraded thicket and bushland, degraded shrubland and low fynbos, degraded unimproved (natural) grassland. The natural class can include bare soils with both sheet and gully erosion; this applies especially to dry areas such as the Karoo. The water body class includes both natural wetlands and dams.

Table 3.4 List of impacts

LOCATION AND TYPE OF IMPACT	NOTE HOW WIDESPREAD OR FREQUENT
Reach impacts	
weirs	
causeways	
bridges	
channel straightening	
Floodplain / channel bank impacts in reach	
cultivation	
vegetation removal	
alien vegetation	
rural or urban settlement	
cattle/game trampling	
Main channel impacts	
Mainstream dam	
Hillslope impacts	
active cultivation	
former cultivation	
livestock grazing	
alien vegetation or forestry plantations	
forest clearing	
urban development	
rural settlement	
dirt roads	
metalled roads	
livestock tracks	
land drainage	
farm dams	
gully erosion	
bare soil and possible sheet erosion	
Other disturbance	

Mainstream dam	Capacity (Mm^3)	date of construction	distance upstream (km)	% catchment captured

Maps available through the South African Biodiversity Institute (SANBI)

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plantations,

mines.

Note that the degradation class refers to degraded forest and woodland, degraded thicket and bushland, degraded shrubland and low fynbos, degraded unimproved (natural) grassland. The natural class can include bare soils with both sheet and gully erosion; this applies especially to dry areas such as the Karoo. The water body class includes both natural wetlands and dams.

South African Atlas of Agrohydrology and Climatology.

The revised South African Atlas of Climatology and Agrohydrology was produced by Schulze (2007). This atlas is available in both hard copy and digital format from the Water Research Commission and provides a comprehensive set of data and maps related to South African hydrology. The most relevant data for a geomorphological assessment include soils, vegetation cover, rainfall, quaternary runoff and sediment yield.

National Review of Land Degradation in South Africa

A National Review of Land Degradation in South Africa and maps of land degradation by magisterial district are available from the Plant Conservation Unit, University of Cape Town http://www.pcu.uct.ac.za/resources/landdeg/consensus.htm This is based on the book by Hoffman T, and Ashwell A. (2001) Nature Divided: Land degradation in South Africa, University of Cape Town Press, Cape Town.

3.7 ASSESSING GEOMORPHOLOGICAL CHANGE AT THE REACH AND SITE SCALE

3.7.1 Flood history

It is important to research the flood history of the river so that you can interpret recent channel changes. When was the last big flood (recurrence interval > 20 years)? Have floods been impacted by upstream and catchment disturbances noted under 3.4?

Consult the hydrologist and, if data are available, construct a flood frequency curve. If there is a gauging station on the river, flood data (daily peak flow) can be obtained directly from the DWA website but be aware that the data quality may be poor and that it is unusual for flood discharge greater than bankfull to be recorded because of the expense of building a gauging weir able to accommodate high flows. Stage height above bankfull is usually given, but not converted to discharge because of a lack of calibration. If there is no gauging station, any hydrological data provided to you will have been simulated using a model. Be aware that simulated data can include large errors, especially in the case of flood discharges. Much of the data on South Africa's national hydrological databases are modelled at a monthly time step, which is not useful for flood analysis.

Supplement hydrological data with other sources. 'Google' the river name and floods, or a town name and floods. The Weather Bureau of South Africa published a compilation of notable weather events from 1500 to 1990 (Weather Bureau 1991), including floods and severe storms, with a database updated to 2001. Flood related data has been extracted and is available in spreadsheet format from the website http://geomorphsa.com/.

Once in the field you should talk to farmers or other local people about their experience of floods.

3.7.2 Historic channel change

Sequential aerial photographs can be used to identify changes to channel pattern, channel dimensions and larger scale morphology. They are also useful for mapping changes to riparian vegetation cover. Aerial photographs are available from the National Geo-spatial Information, South Africa (NGI) (Available: http://www.ngi.gov.za/). The Sales Office should be contacted directly for information on availability of photographs and for ordering digital or hard copy. You will need to send them the top right and bottom left hand corner of the area of interest. Photo pairs are invaluable for looking at detailed relief under a stereoscope.

The earliest aerial photographs in South Africa were flown in the 1940s, with repeat photography approximately every ten years. The scale and quality of photographs is variable. A scale of at least 1:30,000 is required in order to see channel details. Black and white panchromatic photographs are available in hard copy and digitally. The quality of hard copy photographs is usually better than the scanned digital copies. The hard copies can be scanned at a higher resolution in order to enlarge the scale. The latest aerial photographs were flown in 2009 and 2010. These are colour photographs with a resolution of 0.5 m and are available digitally. At present there is no cost for digital imagery other than the cost of sending data.

Note the date and scale of all photographs used. Table 3.5 can be used for this purpose.

Table 3.5 Record of aerial imagery

Date (year and month)	Scale	Quality

4 GAI FIELDWORK AND FIELD FORMS

This chapter describes the fieldwork undertaken at the study site. The minimum time allocated to a site visit is 2 hours. This is likely to be increased for complex or large river systems.

4.1 DETERMINATION OF THE SITE EXTENT

A desktop analysis of the study reach should have been undertaken before the field exercise takes place (see Chapter 3). It is advised that large-scale aerial images of the study reach and site are printed and brought to the field for checking and annotation. Once at the field site, it is necessary to evaluate the character of the site and assess how representative it is of the reach and resource unit.

Walk both upstream and downstream of the study site as far as is possible, or as far as is necessary to gain an impression of the geomorphology of the reach. As a general rule, it is recommended that the person undertaking the assessment should walk at least 6 x channel width in both the upstream and downstream directions from the study site. Morphological sequences such as pool-riffle tend to follow a regular spacing of between five to seven channel widths (Gordon *et al.,* 2004), so a distance of six channel widths should incorporate a full sequence in both directions. This may be difficult for large channels and where access along the banks is restricted. At a minimum, one entire suite of morphological units should be included (e.g. pool-riffle; pool-rapid; step-pool). The entire section assessed becomes the “site” in terms of the GAI.

Site details not already captured during the desktop study should be filled in section 1 and 2 of the field form under site identifiers and reach description.

4.2 FLOW CONDITIONS

The level of flow should be recorded in section 3 of the field form according to the classification flood, spate, high baseflow, low baseflow and no flow. This is important as it gives an indication of site accessibility, how easy it was to observe features and allows available habitat to be related to flow conditions. Table 4.1 provides guidelines for flow classification. Flow clarity is recorded according to three categories: clear (channel bed features easily seen in knee deep water) (0.5 m), cloudy (channel bed features can be seen in shallow water (0.2 m) but not in knee deep water), opaque (channel bed features not visible).

Table 4.1 Flow categories

Flow category	Description
Flood	Water level is close to or exceeds bankfull, causing much of the lower vegetation zone to be inundated. Access to the river is hazardous, many morphological features underwater.
Spate	Raised water levels due to storm runoff, but water contained within the channel. Inset benches and marginal vegetation zone under water. Fast flows may prevent access to river.
High base flow	“Normal” water levels for the wet season. Channel morphology should be discernible. Access to river is possible, but there may be some areas where fast, deep flows present a risk to personal safety.
Low base flow	“Normal” water levels for dry season. Most morphological features exposed and access to most of the channel is possible.
No flow	Water is restricted to isolated pools. Very shallow flow may be present.

4.3 PHOTOGAPHS, PLAN VIEW AND CROSS-SECTION SKETCH

Once you feel familiar with the main features of the site and its extent invest time in taking photographs, making a sketch of the site plan and cross-section. Not only does this provide an important record of the site geomorphology, but it also concentrates attention on key features that are to be described and classified as part of the field exercise.

Use section 5 of the field form to record the photographs, site plan and cross-section. Mark relevant channel morphology and related habitat features. Consult with other specialists to reach conformity in defining boundaries between key habitat types. An example of a sketch is given in Figure 4.1. It is helpful to use a large-scale aerial image as a template. The cross-section sketch can be used later to interpret and annotate surveyed cross-sections used to model flow hydraulics.

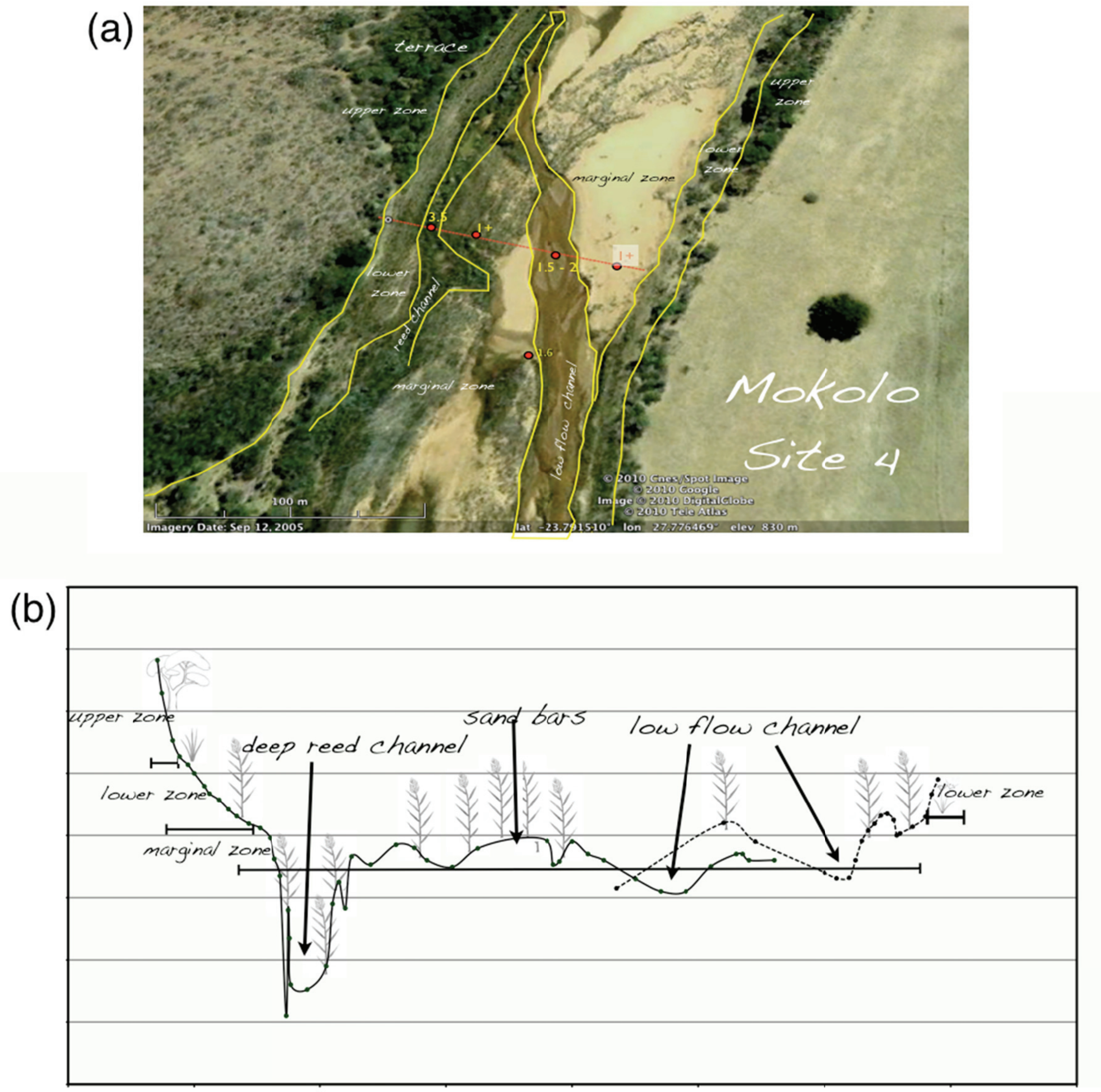

Figure 4.1 **(a) sketch map based on a Google Earth image taken into the field (b) sketch of channel cross-section showing channel features in relation to vegetation zones.**

4.4 CHANNEL DIMENSIONS

Channel dimensions (width and bank height above low water level) should be estimated and the range over the site recorded in section 6 of the field form. The width of riffles or rapids is generally greater than that of pools. Where time, or accessibility, does not allow direct measurement for example with a tape measure or range finder the following categories can be used.

Width (m): <1, 1-2. 2-5, 5-10, 10-20, 20-50, 50-100, >100

Depth (m) <1, 1.5, 1.5-2, >2

4.5 CLASSIFICATION

The reach is described and classified according to four groups of characteristics: valley confinement, channel and reach type, reach type morphological units, habitat. Channel classification is carried out according to the guidelines presented by Wadeson and Rowntree (1999).

4.5.1 Valley confinement

See desktop study. Confirm in the field (section 2 on field form).

4.5.2 Channel pattern

See desktop study. Confirm in the field (section 2 on field form).

4.5.3 Channel type and reach type

Channel type is classified according to channel perimeter materials. Channels formed predominantly in bedrock (bedrock channels) are separated from those formed in alluvial sediments (alluvial channels). Mixed channels include alternating sections of bedrock and alluvium. This channel type is common in South Africa. Channel type is then classified according to the dominant bed material (normally the largest 'common' size class). Sediment classes by grain diameter are given in Table 4.2.

The reach type depends firstly on channel type. The different reach types commonly found in South African rivers are described in Table 4.3 and Table 4.4.

Channel and reach types are recorded in the table in section 7 of the field form.

Table 4.2 Sediment classes by grain diameter

Size class	Grain diameter (mm)	Feel or analogy
Boulder	>256	Too large to pick up
Cobble	64-256	Rugby ball
Coarse gravel	16-64	Cricket ball
Medium gravel	8-16	Golf ball
Fine gravel	2-8	Pea
Coarse sand	0.5-2	Brown sugar
Medium sand	0.125-0.500	White sugar
Fine sand	0.063-0.125	Caster sugar
Silt	0.002-0.063	silky
Clay	<0.002	sticky

4.5.4 Morphological Units

Morphological units are the channel components that are most closely associated with habitat. The composition and arrangement of morphological units determine the flow hydraulics at any given discharge, that is, the distribution of depth and velocity across the streambed. Morphological units also provide the substratum for organisms. They are identified separately for bedrock and alluvial sections. Descriptions of different instream morphological units are given in Table 4.5 and 4.6. The morphological units are noted in section 8 of the field form included in the classification section.

Channel bank morphology is classified in terms of benches, floodplain and terraces. These features are defined in terms of lateral extent and estimated frequency of inundation (Figure 1.1 and Figure 4.2 and Table 4.6). Channel banks are described further in terms of their sediment composition and vegetation cover (also for bars) (section 9 and 10 of the field form). Together these determine bank stability.

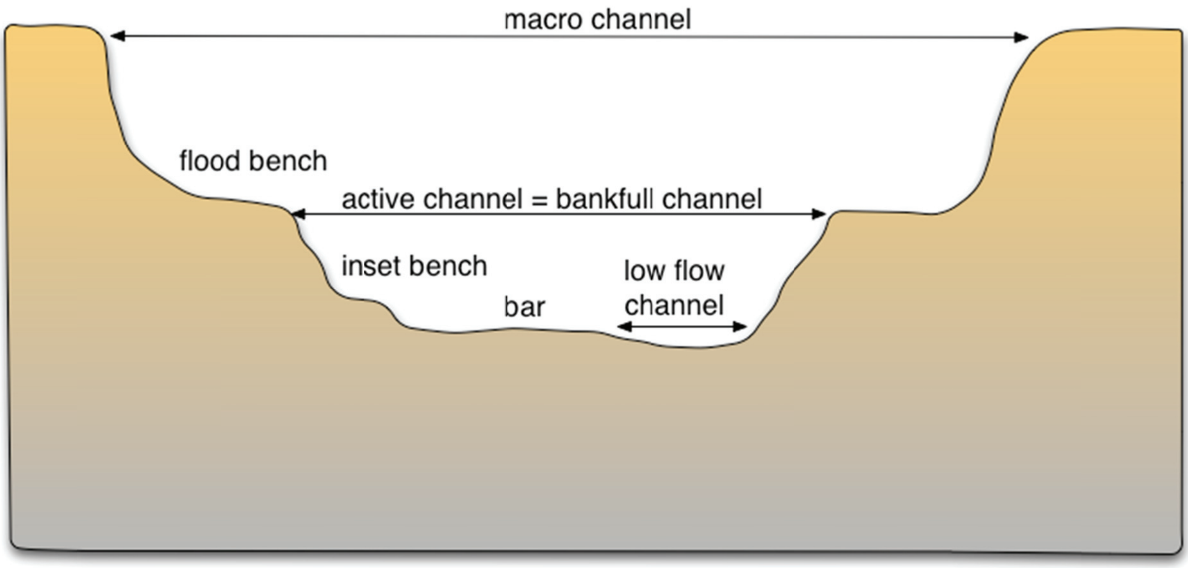

Figure 4.2 Channel features

4.5.5 Gallery of images for channel classification

A gallery of images of different channel features can be found at the website www.geomorphsa.com – Geomorphological Tools for River Management in South Africa. This site will be continually updated to provide new examples.

Table 4.3 Summary of the reach types found in alluvial systems (modified from Rowntree and Wadeson 1999, 2000)

REACH TYPE	DESCRIPTION
Step-Pool	Characterised by large clasts that are organised into discrete channel-spanning accumulations that form a series of steps separating pools containing finer material.
Plane-Bed	Characterised by plane-bed morphologies in cobble or small boulder channels lacking well-defined bedforms. Instream bars uncommon.
Pool-Riffle	Characterised by an undulating bed that defines a sequence of bars (riffles) and pools. Often associated with point bars in meandering channels.
Pool-rapid	Channels are characterised by long pools backed up behind channel-spanning steep boulder deposits forming rapids. Lateral bars and mid-channel bars commonly associated with pools.
Regime	Occur in either sand or gravel. The channel exhibits a succession of bedforms with increasing flow velocity. The channel is characterised by low relative roughness. Plane-bed morphology, sand waves, mid-channel bars or braid bars may all be characteristic.

Table 4.4 Summary of the reach types found in bedrock-controlled systems (modified from Rowntree and Wadeson 1999)

REACH TYPE	DESCRIPTION
Cascade	High-gradient streams dominated by waterfalls, cataracts, plunge pools and bedrock pools. May include bedrock core step-pool features.
Flat Bedrock	Predominantly bedrock channel with a relatively smooth bed. Significant falls or rapids are absent.
Bedrock Fall	A steep channel where water flows directly on bedrock with falls and plunge pools.
Pool-Rapid	Channels are characterised by long pools backed up behind channel-spanning bedrock intrusions with sufficient gradient to form rapids.

Table 4.5 Morphological units in alluvial systems (modified from Rowntree and Wadeson 1999)

MORPHOLOGICAL UNIT	DESCRIPTION
Step	Formed by large clasts (cobble and boulder) organized into discrete channel-spanning accumulations.
Rapid	Local steepening of the channel long profile over boulders, local roughness elements drowned out at intermediate to high flows.
Plane bed	Topographically-uniform bed, lacking well defined scour or depositional features.
Riffle	A transverse bar formed of gravel or cobble, commonly separating pools upstream and downstream.
Run	A section of channel of moderate gradient with a uniform trapezoidal cross-section and low roughness relative to depth.
Pool	Topographical low point in an alluvial channel caused by scour; characterised by relatively finer bed material.
Flat sand bed	Sands or fine gravels fill bed without forming distinct morphological features. Dunes or ripples may be present.
Backwater	Morphologically detached side channel that is connected at lower end to the main flow.
Point bar	A bar formed on the inside of meander bends in association with pools. Lateral growth into the channel is associated with erosion on the opposite bank and migration of meander loops across the floodplain.
Lateral bar or channel side bar	Accumulation of sediment attached to the channel margins, often alternating from one side to the other so as to induce a sinuous thalweg channel.
Mid-channel bar	Single bars formed within the middle of the channel, with strong flow on either side.
Tributary bar	Forms immediately downstream of a tributary junction due to the input of coarse material into a lower angled channel.
Lee bar	Accumulation of sediment in the lee of a flow obstruction.
Secondary channel	High flow distributary channel on the inside of point bars or lateral bars; may form a backwater at low flows.
Islands	Mid-channel bars which have become stabilised due to vegetation growth and which are submerged only at high flows that cause overbank flooding (i.e. bank-full flows).

Table 4.6 Morphological units in bedrock controlled systems (modified from Rowntree and Wadeson 1999)

MORPHOLOGICAL UNIT	DESCRIPTION
Waterfall	Abrupt discontinuity in channel slope; water falls vertically; never drowned out at high flows. Height of fall significantly greater than the channel depth.
Rock steps	Step-like succession of small waterfalls drowned out at bankfull flows, height of fall less than channel depth.
Rapid	Local steepening of the channel long profile over bedrock, local roughness elements drowned out at intermediate to high flows.
Bedrock pool	Area of deeper flow forming behind resistant strata lying across the channel (includes plunge pools below waterfalls).
Bedrock pavement	Horizontal or near-horizontal area of exposed bedrock.
Bedrock island/ core bar	Accumulation of finer sediment on top of bedrock.
Backwater	Morphologically detached side channel which is connected at lower end to the main flow
Bedrock run	A channel formed in bedrock with a moderate gradient, a uniform trapezoidal cross-section and low roughness relative to depth.

Table 4.7 Channel bank morphology

Morphological feature	Extent (m)	Frequency of inundation	Comment
Inset bench	normally <3 m	< 1 per year	Formed within the active channel
Flood bench	normally < 50 m	1-3 years	Top of active channel = bankfull Confined within macro-channel or valley sides
Floodplain	not specified	1-3 years	Top of active channel = bankfull, Unconfined
Terrace	not specified	> 3 years	May be multiple terraces
Anthropogenic terrace	not specified	> 3 years	Frequency of floodplain inundation reduced due to artificial structures or other engineering intervention

4.5.6 Geohabitat

Geohabitat is a transient feature related to flow so it is important to record the level of flow as described in section 4.2. Instream habitat is described in terms of flow depth, flow type (related to velocity) and bed substrate. Riparian vegetation is described for morphological units that reflect varying flow inundation frequency. The extent of each habitat type is described in terms of three categories widespread, frequent and infrequent according to their aerial extent either instream or along the banks as appropriate. The relevant table can be found in section 11 of the field form.

4.6 IMPACT EVALUATION AND RATING THE DRIVER METRICS

This section explains the conditions that are likely to impact on each of the driver metrics (connectivity, sediment supply and channel stability) and can be used to guide the rating of these metrics. Causes of modification and associated impacts are described below for each driver (section 4.6.1).

Before assessing impacts the assessor's knowledge of the river system is recorded in Table 1 in section 12 of the field form. This will assist in assessing confidence levels later on.

Section 12 of the field form lists potential impacts for each driver metrics of GAI. The combined effect of these impacts on each metric should be rated 1-5 (or -5 to +5) according to criteria given in Table 4.8. Where relevant, a positive value indicates an increase in a given metric relative to reference, a negative value a decrease. Guidelines are provided on the field forms to assist rating each impact. Table 2 and Table 3 in section 12 of the field form give guidelines for deriving ratings. Expert judgment should always be used to derive the final score. In some cases two impacts may act to cancel each other out (for example increased hillslope erosion would increase sediment supply but farm dams would store much of that sediment before it reached the river). The comment box should be used to record the direction of change for each metric and how a decision was made regarding the final rating.

In some cases a driver impact may have been reduced, possibly through some sort of rehabilitation measure, but the modified channel condition persists. This may be due to a geomorphic threshold being crossed in the past, preventing recovery, or to a lag in the system causing recovery to take place over a period of time. It is difficult to prescribe guidelines to cover such a case; the assessor must use his or her judgment in order to assign an appropriate rating.

The rating should be assessed in terms of the impact on the river reach within which the study site is located or on the site, as indicated on the field form. Activities occurring upstream of the reach will have a decreasing impact, depending on distance from the reach. Large dams form a discontinuity on upstream-downstream interactions, so that activities upstream of a large dam can effectively be ignored.

Consultation with the hydrologist will assist in assessing the impact of connectivity changes on flood magnitude and frequency; consultation with the riparian vegetation specialist will assist with assessing channel stability changes due to vegetation change.

Note that the rating should be done with respect to the effect of possible geomorphic change on ecosystem functioning and therefore the focus is instream and riparian habitat.

Table 4.8 Guidelines for rating metrics in GAI (modified from Kleynhans 1996, 1999)

Rating (range) = modification from reference	General habitat modification	Expected geomorphological response to change in driver
0 (0-0.5) = none	No discernible impact or the modification is located in such a way that it has no impact on habitat quality, diversity, size and variability.	Changes to channel morphology have no discernible impact on habitat quality, diversity, size and variability.
1 (0.5-1.5) = small	The modification is limited to very few localities and the impact on habitat quality, diversity, size and variability is also very small.	Localized or small scale changes to channel morphology that have a small impact on habitat quality, diversity, size and variability.
2 (1.6-2.5) = moderate	The modifications are present at a small number of localities and the impact on habitat quality, diversity, size and variability is also limited.	Changes to drivers or perimeter conditions have resulted in a change in channel dimensions, but habitat quality, diversity, and variability are largely unchanged.
3 (2.6-3.5) = large	Clearly detrimental impact on habitat quality, diversity, size and variability. Large areas are, however, not influenced.	Changes to drivers or perimeter conditions have resulted in a definite change to habitat quality, diversity, size and/or variability.
4 (3.6-4.5) = serious	The modification is frequently present and the habitat quality, diversity, size and variability in almost the whole of the defined area are affected. Only small areas are not influenced.	Changes to drivers or perimeter conditions have resulted in a change in channel state (e.g. from supply to transport limited channel or braided to meandering channel). Widespread changes to habitat quality, diversity, size and variability, but still able to support a sustainable, if modified, ecosystem.
5 (4.6-5) = extreme	The modification is present overall with a high intensity. The habitat quality, diversity, size and variability in almost the whole of the defined section are influenced detrimentally.	Irreversible changes resulting in a widespread transformation of channel morphology and associated habitats. Loss of habitat diversity seriously compromises ability to support a complex ecosystem.

4.6.1 Causes of modification and associated impacts

4.6.1.1 Connectivity

The connectivity metric group consists of four separate metrics: hillslope-channel connectivity, longitudinal connectivity, lateral connectivity and vertical connectivity. Causes of modification and associated impacts will be described for each in turn. Level III assessors ignore hillslope-channel connectivity and vertical connectivity.

Hillslope-channel connectivity

Hillslope-channel connectivity describes the connectivity between the hillslopes that generate runoff and sediment and the channel network. It is a measure of sediment delivery. The potential flow and sediment inputs to the channels increase as connectivity increases whereas the potential for storage of water and sediment is inversely related to connectivity.

Hillslope connectivity is naturally highest for confined v-shaped valleys where there is direct contact between the slope and the channel. Natural connectivity decreases as the valley floor widens and the channel no longer makes contact with the hillslopes.

Anthropogenic factors that increase hydrological connectivity include processes that increase surface runoff such as surface hardening or loss of vegetation cover, and processes that increase the drainage network for the movement of surface flow. This can include gully erosion, where gullies extend to the slope foot, drainage ditches, and footpaths, cattle tracks and roads that are orientated up and down slope. Similar factors increase sediment connectivity because surface flow is required to transport the sediment. Landslides that reach the channel also increase sediment connectivity.

Barriers affecting low order tributaries (normally up to third order on a 1:50 000 topographic map) are also included under the category of hilllslope-channel connectivity. These include farm dams and impacts at tributary junctions. Farm dams, although small in size, are often large in number and together can have a significant impact on downstream flows and sediment. Tributary junctions play an important role in regulating connectivity within a stream network. An example of changing connectivity can be given for an alluvial fan, which under natural conditions can act as a buffer between the tributary and the main channel. Channelization of alluvial fans increases connectivity whereas the construction of levees or berms across a fan channels would decrease connectivity.

Impacts associated with increased hillslope-channel connectivity include increased flood peaks and increased potential for sediment delivery. The inverse is true for decreased connectivity.

Longitudinal connectivity

Longitudinal connectivity refers to the upstream-downstream connectivity either between reaches or within reaches. The biggest impact on longitudinal connectivity between reaches is dam construction. The size of the impact can be measured in terms of the reservoir capacity relative to the mean annual runoff of the river at the dam site. The distance of the study reach below the dam is an important consideration as the impact of a dam decreases with distance downstream.

In cases where longitudinal connectivity is decreased, the main effect is firstly to reduce the magnitude and frequency of floods, thus reducing the energy for geomorphic work, and secondly to trap sediment and reduce the supply of sediment to downstream reaches. A comprehensive discussion of geomorphological impact of dams is given by Petts and Gurnell (1995), Dollar and Rowntree (2003) and Beck and Basson (2003).

The impact on floods depends to some extent on how the dam is operated, but normally it is the smaller, most frequent floods that are most affected. Two flood frequencies have been identified as being well correlated to channel form and therefore believed to be important drivers of channel processes – the flood with a recurrence interval of c. 1.5 years and the mean annual flood, with a recurrence interval of 3.4 years. A number of studies worldwide have shown that channel size (width and depth) and the spatial pattern of channel features (e.g. pools and riffle spacing) are well correlated to the discharge with these flood frequencies. Dams will inevitably reduce both the 1.5-year and 3.4-year flood, resulting in a contraction of channel size and a restructuring of instream morphology. The most extreme floods (> 1 in 50 year recurrence interval) will be little impacted. The flood regime will therefore also become more variable.

The impact of a dam on sediment trapping depends on its trap efficiency, which increases with the reservoir capacity. In most cases 100% of bedload will be trapped (sand and coarser) and often over 90% of the fine suspended load. This means that water leaving the dam is deficient in sediment. Bed and bank erosion commonly occur in the reaches immediately downstream of the dam. Winnowing of fine sediment from channel beds composed of mixed grain sizes results in a more uniform coarse armour at the bed surface.

Further downstream the effect of the dam depends on the relative inputs of flood flows and sediment from tributaries. Reduced flood magnitude due to the dam often results in sediment aggradation, especially at tributary junctions.

Weirs, causeways and bridges cause within-reach changes to longitudinal connectivity. These normally have a local effect on flow and sediment movement and can result in local changes to channel morphology. Sediment is deposited upstream of the obstruction, filling in pools and forming bars; erosion occurs downstream of an obstruction, causing bed armouring, bank erosion or channel incision.

Lateral connectivity

Lateral connectivity describes the connectivity between the main channel and the riparian zone. It is the result of the interaction between elevated flows (floods) and the shape of the channel cross-section. Lateral connectivity determines the frequency of inundation of different geomorphic and vegetation zones.

Changes to lateral connectivity may be the result of changes to the magnitude-frequency regime of floods, or to change in the structure of the channel cross-section. The latter may be caused by channel incision, channel straightening, or the construction of berms or levees along the top of the channel bank. Channel aggradation (sediment deposition) can result in a decrease in channel depth and increased lateral connectivity, other factors remaining constant.

It is important to recognize that channel incision can result from natural processes related to climate change and or steepening of the valley floor due to long-term sediment aggradation. If incision is observed the likely cause should be identified before assigning a rating.

Vertical connectivity

Vertical connectivity describes the potential for interaction between the channel surface and the underlying hyporheic zone. This zone can act as an important habitat for aquatic organisms, especially in times of stress. Vertical connectivity is determined by the depth of permeable sediments that allow free movement of water and organisms. Vertical connectivity can be lost if coarse sediment (sand or coarser) is stripped to expose bedrock or, conversely, if interstitial spaces are filled in with fine sediments that impede movement. Channel hardening through a concrete lining would result in an extreme loss of vertical connectivity.

4.6.1.2 Sediment supply

By definition, alluvial channels are constructed within the sediment that they carry; bedrock channels occur where the transport capacity of the flow over time exceeds the sediment supply. In alluvial channels, channel pattern and channel morphology are all related to the amount and calibre (size) of sediment being transported and deposited in the reach. Changes to the supply of fine sediment can have a significant effect on the composition and structure of the bed and therefore on habitat quality for a range of instream organisms. Sediment composition of the riparian zone affects the water holding capacity of the soils and nutrient availability. Sediment is therefore a key metric to consider.

The origin of coarse gravel, cobble and boulder found on the bed of a river is normally from mass movements on steep hillslopes well coupled to the channel, or from the erosion of coarse deposits in river banks. Sheet and rill erosion do not have the capacity to transport material of this size, though gullies can transport gravel and possibly small cobble. Except in rare cases, the coarse bed material load is unlikely to be significantly impacted by anthropogenic activity.

The load of sand, silt and clay can all be impacted by anthropogenic activity that increases rates of erosion on the catchment slopes. This material can be transported to the channel by sheet and rill flow and, once in the channel, can be transported rapidly downstream during floods as either suspended load or, in the case of sand, as bed load. During the recession limb of the flood hydrograph silt and clay will be deposited in low velocity zones.

The main anthropogenic cause of slope erosion is a land use change that reduces vegetation cover and exposes bare soil to erosive forces. These changes include increased cultivation, especially in the absence of erosion control, increased grazing pressure, spread of alien vegetation or plantation forestry where this results in a loss of ground cover. Dirt roads can also provide a source of sediment.

Bank erosion due to vegetation removal, spread of alien vegetation, cattle trampling or river regulation is also considered as a source of sediment. When assessing bank erosion it is important to differentiate natural processes from those resulting from anthropogenic activity. A naturally meandering channel in equilibrium with the flow regime will erode the bank on the outside of the meander bend, but deposit sediment as a point bar on the inside of the bend. Erosion on opposite banks indicates disequilibrium.

Under natural conditions channels can migrate laterally and may undercut hillslopes, terraces or alluvial fans, giving a false impression of instability. Only if the lateral migration is the result of human activity (for example channel realignment) should this form of bank erosion be factored into the assessment.

Sand and gravel mining can cause a significant depletion of sediment that will have consequences downstream. Increased erosion capacity can cause bed scour, deepening pools, or loss of bar formations. Bank erosion could also be a consequence of sediment mining.

Greatest importance should be placed on changes to sediment supply within the study reach. Changes further up river will have a decreasing impact on the study reach due to sediment storage within the system. Changes upstream of a major break in longitudinal connectivity (e.g. a large dam) should be ignored. It is important not to conflate changes to connectivity that affect sediment delivery (hillslope-channel connectivity) with changes to the sediment supply itself as this will result in double accounting.

4.6.1.3 Channel stability

Channel stability describes the potential for transport or erosion of the channel bed, bars, banks or flood zones. This is directly related to the shear strength of the relevant material and depends largely on the size distribution and packing of sediments and vegetation. Unfortunately both of these attributes are subject to natural change so that it is difficult to assess the extent to which they have been modified from reference, especially by a non-specialist (in the case of vegetation). Human induced changes to bed and bank sediment are especially difficult to identify. For this reason the approach taken is to focus on human related processes or activities that are likely to have a direct impact on the density and structure of the vegetation cover or other causes of change to bank or bed stability due to engineering interventions (e.g. gabions or concrete lined channels). Consultation with a riparian vegetation specialist should help to confirm the extent to which vegetation has changed from reference.

The stability of the channel bed and instream bars is most likely to be affected by changes in the sediment composition and structure. An increase in sand or gravel relative to cobble will increase the mobility of the bed or bar. Conversely, armouring below a dam will decrease bed mobility. Bed stability is increased by the formation of imbricated structures (Figure 3.1), whereas loose packing increases the potential for movement. Gordon *et al.* (2004) explain that stable bed structures are best developed when there is a relatively gentle flood recession that allows sorting and realignment processes to take place. A sharp drop in competence caused by a steep recession limb results in particles being deposited in their position of transport. Bed structures could therefore be affected by dam operations that change the shape of the flood hydrograph.

Bars can also be stabilized by vegetation and in time may become out-of-channel features or islands, with a decreased frequency of inundation.

The channel bed and bars are assessed together as the boundary between them depends on flow conditions. For example a bar may be exposed during low flow and is seen as a distinct feature but at higher flows it becomes an extension of the channel bed.

The main impact on the resistance of channel banks is due to changes in bank vegetation. A grass cover affords some resistance, but tree roots are the most effective in stabilizing a bank. The depth of the adventitious root mat is important. Trees with relatively shallow adventitious roots such as *Acacia mearnsii* or *Pinus* species are often associated with undercutting and bank collapse, with the fallen trees forming debris dams. Willow species such as *Salix capensis* with an extensive deep root system that extends below water level increases bank stability (Rowntree, 1991; Rowntree and Dollar, 1996; 1999). The effect of changing vegetation will depend on the cohesion of the bank sediments. Banks composed of uncohesive sand will be most affected, whereas cohesive banks composed of a silt-clay mixture will be less so and banks composed of bedrock are unlikely to be affected by vegetation. Bank slope is another important factor. The steeper the bank, the greater will be the immediate impact of increasing or decreasing vegetation. In the longer term, the bank slope will adjust to the new conditions.

The stability of flood zones will be increased by any vegetation that forms a good surface cover and has a near surface root mat that increases the shear strength of the surface soil horizon.

4.7 50SIGNING CONFIDENCE LEVELS

Confidence levels are assigned to the various ratings of metrics according to the guidelines given in Table 4.9. The confidence level is based on the amount of data available on which to make the assessment and the level of understanding about the type of river being assessed.

Table 4.9 Guidelines for confidence scoring

Level of understanding – expert knowledge		Availability of data				
		poor		moderate	good	
		1	2	3	4	5
Has a poor understanding of how drivers have changed from reference and of the likely impact on channel morphology and geohabitats.	1	1	1.5	2	2.5	3
	2	1.5	2	2.5	3	3.5
Has a limited understanding of how drivers have changed from reference and of the likely impact on channel morphology and geohabitats.	3	2	2.5	3	3.5	4
Has a good understanding of how drivers have changed from reference and of the likely impact on channel morphology and geohabitats.	4	2.5	3	3.5	4	4.5
	5	3	3.5	4	4.5	5

4.8 ASSIGNING FLOW DEPENDENCE

Flow dependence is a measure of the extent to which observed impacts are the result of changes to flow. The value is given as a percentage. This is important when GAI is used in the context of an environmental water requirement exercise, as the main driver that is to be managed is flow. Many GAI metrics are non-flow related. The non-flow related component of the GAI output also provides pointers to possible catchment related interventions that would be required to improve river condition.

Flow related metrics include the following:

Hillslope-channel connectivity where:

- metrics affect storm runoff

Longitudinal connectivity where:

- metrics impact on the magnitude and frequency of floods.

Lateral connectivity where:

- channel incision is the response to increased flood magnitude
- channel aggradation is the response to decreased flood magnitude

- increased/decreased overbank inundation is due to changes in flood magnitude.

Vertical connectivity where:

- sediment stripping is due to increased flood magnitude
- sediment deposition is due to decreased flood magnitude.

Sediment supply where:

- changes in the rate of hillslope erosion is due to increased/decreased storm runoff
- changes to the rate of channel erosion is due to increased/decreased flood magnitude in main channel.

Channel stability where:

- increased or reduced water availability impacts on riparian vegetation.

4.9 RECONSTRUCTING THE REFERENCE CONDITION (LEVEL IV ONLY)

Once the different impacts have been identified the reference condition can be reconstructed using the procedure outlined below. Section 13 of the GAI level IV field form is used to record the reference condition.

The reference condition is the condition of the river ecosystem in the absence of anthropogenic impacts. It provides a benchmark against which change in the system can be evaluated. As indicated above (2.3), imagining and recreating the reference condition can be a difficult process due to the dynamic nature of river channels and the difficulty of disentangling the effects of natural and anthropogenic disturbance. For this reason two approaches are taken to assessing the reference condition of a geomorphic system.

1. Assess the expected channel morphology from the topographical setting of the study reach. This is based primarily on channel gradient (slope), but also on the degree of valley confinement as explained in section 2.2 (see Table 4.11). A limitation of this method is that there is a range of channel types and condition that can be expected for any given slope-valley confinement combination, and the level of detail does not translate well to the geohabitat level.

2. Use available historic evidence to reconstruct the previous condition of the channel. Aerial photographs are a key resource for wide, open channels, but are of limited use in narrow channels or where there is a dense overhead canopy. Evidence of former condition can also be obtained from local long-term residents who are familiar with the river. Knowledge of historic presence of species may also provide pointers to previous geomorphology. For example has there been a loss of a fish species that required deep pools or clean cobble? Talk to the ecological specialists to see if they can shed any light here.

3. Consider the external drivers of the geomorphic system that impact on the interconnectivity between different system components, on available energy for geomorphic work, the supply of sediment into the system, and the resistance of the system to change. Table 4.10, in combination with Table 4.11, can be used to derive an assumed reference condition in the absence of observed impacts.

Table 4.10 Deriving the reference conditions for GAI

IMPACTS TO FACTOR OUT	MORPHOLOGICAL RESPONSE METRIC	DESCRIPTION OF STATE CHANGE
1. Increased or decreased connectivity	Instream morphological change Substrate changes Channel geometry changes	1. Describe how the channel morphology and associated habitat would change in the absence of observed changes to connectivity.
	Riparian zone morphological change Substrate changes Channel geometry changes	
2. Increased or decreased sediment supply	Instream morphological change Substrate changes Channel geometry changes	2. Describe how the channel morphology and associated habitat would change in the absence of observed changes to sediment supply.
	Riparian zone morphological change Substrate changes Channel geometry changes	
3. Increased or decreased channel stability	Instream morphological change Substrate changes Channel geometry changes	3. Describe how the channel morphology and associated habitat would change in the absence of observed changes to channel stability.
	Riparian zone morphological change Substrate changes Channel geometry changes	

The following steps provide a guideline to derive the reference condition.

1. Classify the river zone from the river gradient and valley form (Table 4.11).

2. Consult the desk-top study to identify any natural events that may have caused changes to the channel (Section 3.7)

3. Use the field form to identify observed impacts that will affect connectivity, sediment supply and channel stability.

4. Record the predicted condition of the channel and its associated geohabitats in the absence of the listed impacts. Refer to Table 4.11 for guidelines as to the expected channel characteristics. The impacts should normally be considered in the order indicated (1-3), taking into consideration the effect of removing the previous impact.

Table 4.11 River Zonation classification (after Rowntree and Wadeson, 1999)

Longitudinal zone	Macro-reach characteristics			Characteristic channel features
	Valley form	Gradient class	Zone class	
A. Zonation associated with a 'normal' profile				
Source zone	V1	not specified	S	Low gradient, upland plateau or upland basin able to store water. Spongy or peaty hydromorphic soils.
Mountain headwater stream	V6, V7	> 0.1	A	Very steep gradient streams 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	V6, V7	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	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	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	V4, V2	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	V1, V2 V3	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.
B. Additional zones associated with a rejuvenated profile				
Rejuvenated bedrock fall / cascades	V5	>0.02	Ar/Br/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	V4, V5	0.001-0.02	Dr/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	V1, V2, V3	< 0.005	Fr	A low gradient channel associated with high altitude plateau areas. Commonly associated with meandering channels and floodplain wetlands. Down cutting constrained by a barrier such as a dolerite dike.

4.10 ASSESSING PRESENT GEOHABITAT CONDITION AND CHANGE TO CHANNEL MORPHOLOGY

4.10.1 Background

Channel morphology provides the physical habitat template for riparian and instream ecosystems. It is therefore important that an assessment is made of the extent to which the channel morphology is thought to have changed due to anthropogenic impacts. This assessment is made independently from the assessment of driver impacts. Because it may be difficult to separate natural change from anthropogenic change, the confidence level for the assessment of morphological change is often of low.

Changes to the substrate on the channel bed, bars, banks and flood zones may take place relatively quickly in response to a driver change as the bed is sensitive to changes in sediment load and the transport capacity of the flow. Time scales of change will be in the range of 1 to 20 years. The morphological response to erosion processes is likely to be faster than to deposition processes.

Significant changes that affect instream habitat include:

- Loss of open gravel or cobble due to infilling with sand or silt; silt would have the most negative impact
- Blanket covering of coarse gravel and cobble by sand or silt
- Loss of bed imbrication in coarse gravel and cobble beds causing the bed to become more mobile
- Stripping of sediment to expose bedrock

Significant changes that affect riparian habitat include:

- Shift in composition of deposited sediment from sand to silt or vice-versa
- Increase or decrease in rate of sediment deposition

Changes to channel geometry are normally the longer term response to changes in the flow regime, in particular the change in flood magnitude and frequency. The time scale of change is normally in the range of 10 to 50 years. This applies to both the response to a driver change and subsequent recovery if the stress is removed.

Significant changes that affect instream habitat include:

- Changes to the channel width, depth and roughness that directly affect the flow depth and velocity for a given discharge.
- Changes to the channel morphology that affect the spatial pattern of velocity-depth flow types.
- Loss or gain of secondary channels that provide refuge and increase habitat variability

Significant changes that affect riparian habitat include:

- Loss or gain of inset benches
- Undercutting and steepening of the bank slope or reduction in bank slope
- Reduction in width of flood bench due to lateral erosion by channel
- Development of meander cutoffs, infilling of oxbow lakes

4.10.2 Assessment

Assessing change to channel morphology is a two-step process. First, the observed condition of geohabitat is assessed irrespective of the cause using the table in section 14 of the field form (section 13 for level III). Separate assessments are made for sediment related attributes and channel geometry and for instream and riparian habitat.

In the second step, the impact of human activity on channel condition and geohabitat is assessed. Changes should be made in the context of the reconstructed reference condition (section 4.9). A rating should be ascribed to each metric group and recorded in section15 of the field form (section 14 for level III). The first step is based on direct observation and does not require expert judgment. It serves to keep a record of geohabitat condition and can be used as a monitoring tool. The second step requires expert judgment to interpret human induced change. The results of this second assessment are used directly to derive a PES score that can be compared to that derived from the driver metric groups.

As with the driver metrics, a confidence rating and flow dependency score should be given.

4.11 STORING FIELD FORM DATA

All the field form data must be transferred to the GAI Excel spreadsheet (see populating the model in Chapter 5).

5 POPULATING THE MODEL

The GAI "model", i.e. spreadsheet, is populated using data recorded on the field forms. The first five worksheets are laid out in the same format as the field forms so that data can be transferred directly. These worksheets provide a record of field observations and are not used directly in the GAI model. The information is used to guide the weighting and rating the metrics in the remaining worksheets.

The spreadsheet has a pale yellow background with blank (white) blocks that are filled in by the user. Green cells indicate that a value will be copied from elsewhere in the spreadsheet, blue cells contain formulae. **Do not type in the coloured cells** as this may result in loss of formulae used to calculate the metrics and the final GAI score.

5.1 PRELIMINARIES

5.1.1 Site identifiers

Transfer the data recorded on section 1 of the field form directly into the Classification worksheet.

5.1.2 Field sketches and photographs

Scan the field sketches and insert into the worksheet called Field Sketches. This will provide an electronic copy that can be stored. Insert photos into the same worksheet,

5.1.3 Classification

Transfer the data recorded in sections 6-11 of the field form directly into the Classification worksheet.

5.1.4 Weighting driver metric groups

Before the metrics themselves are rated it is necessary to rank and weight the metric groups. The weighting metric groups must be done in accordance with the channel type, not the perceived rating of the impacts. The weightings are therefore generic for channel types. Ranks and weightings are entered into the WEIGHTING worksheet.

If a metric is thought to be irrelevant for the system under consideration assign a weighting of 0.

Guidelines for the ranking and weighting of drivers are presented below. Normally changes to system connectivity and changes to the sediment balance would be ranked 1 and 2 respectively. Some general rules are given as follows:

- System connectivity normally has a high ranking because it integrates many aspects of geomorphic river condition.

- Sediment supply will have a higher weighting in a low gradient, lowland alluvial system, where the bed is dominated by sands and gravels. It will have a lower weighting in higher gradient and bedrock systems that are likely to be supply-limited.

- Vegetation related channel stability will have a relatively high weighting for channels with uncohesive banks, as bank stability will be susceptible to changes in vegetation cover and bank steepening. It will normally have a low weighting in bedrock channels which have a stable perimeter.

Always remember that the goal of GAI is to assess geomorphological change in relation to habitat for aquatic and riparian species. Where possible consult with the ecological specialist to ascertain habitat requirements for key species. These requirements may provide additional guidance as to how to assign weightings.

5.1.5 Guidelines weighting metrics within groups

In a level IV assessment metrics within each group are weighted and values entered into the WEIGHTING worksheet. In level III all metrics are assumed to have the same weight.

Guidelines for weighting System Connectivity

- Weightings depend partly on the channel classification.

- Longitudinal (upstream-downstream) connectivity will normally be ranked high, except in headwater streams.

- Confined channels will have a high rank for changes to hillslope-channel connectivity.

- The weighting for within-reach connectivity will be highest in moderate to low gradient channels.

- Lateral (channel-floodplain) connectivity will be given a relatively high weight in unconfined channels with a wide floodplain, but will be given a low weight in confined or naturally incised channels.

- Vertical connectivity is more important in alluvial channels compared to bedrock channels for which it is much less important.

Guidelines for weighting sediment supply

- Hillslope sediment will have a high relative weighting where valley confinement is high because of good hillslope-channel connectivity, resulting in high sediment delivery. Low valley confinement, gentle slopes and a low density of tributary streams will reduce the weighting for hillslope sediment. Increase the weighting in mountain and foothill river zones and also gorges.

- The weighting for river bank sediment supply will increase in the lower gradient river zones where valley confinement is also lower. These would include lower foothill, lowland river and upland floodplain zones.

- The weighting for channel sediment (in all cases will be a decrease) will only apply to sand and gravel bed channels in lowland zones, where it can be ranked equal to bank erosion. However, if there is no sediment extraction the weighting should be zero.

Guidelines for weighting channel stability

- In foothill, lower foothill and lowland zones changes to bed or bar mobility due to vegetation would have a significant effect on instream habitat and bed mobility and should therefore be given a high weighting in these zones. Braided and wandering channels, or meandering channels with well-developed point bars, will be most vulnerable to change.

- In unconfined lowland river zones and upland floodplain zones changes to bank stability will have a significant effect on riparian habitat and should be given a high weighting. Where foothill and lower foothill zones have a significant valley floor providing habitat for riparian vegetation, a higher weighting should be given to bank stability.

- Floodplain stability would normally be given the lowest weighting. If there are no flood zones above the bankfull level, floodplain stability should be given a weighting of 0, for example on a V-shaped mountain stream or confined gorge in a lowland area.

5.1.6 Impacts

Transfer the data recorded in section 12 of the field forms directly in to the RATING worksheet.

5.1.7 Reference condition

Transfer the data recorded in section 12 (level IV) of the field forms directly in to the REF CONDITION worksheet.

5.2 RATING DRIVER METRICS

Ratings, flow dependence and confidence levels for each driver metric should have been recorded in section 12 of the field form. Guidelines for rating are provided on the field forms. These values can now be transferred directly to the RATING worksheet in the GAI spreadsheet. Ratings for morphological change are entered in the same way. Note that these values are carried forward automatically to the METRIC (level IV) and PES worksheets. A summary of reasons for rating should be recorded in the METRIC worksheet. This worksheet provides an overview of ratings, flow dependency and confidence levels.

5.3 GEOMORPHOLOGY PES

The final geomorphology driver status is derived by combining the separate ratings estimated for the three different driver metrics – system connectivity, reach sediment balance, channel stability. Once weightings and ratings have been entered in the relevant worksheets, the weighted rating for each metric group is calculated and automatically transferred to the "Final Geomorph PES" worksheet where the PES for the study site or reach is calculated. The percentage flow-related and confidence values are also calculated from the values derived for the separate geomorphology metrics.

The integrated PES derived from the three metric groups – connectivity, sediment supply and channel stability – should now be compared to the PES calculated from the morphological change ratings, which is also calculated automatically and appears below the other metric groups. If there is a discrepancy in category (A-F), the weightings and ratings for the different metrics should be revisited. Those for which a low confidence level was assigned should be examined first. Justifiable changes should be made until the two categories match, and a record of changes made in the relevant comment box. If it is not possible to match the two categories, the one with the highest overall confidence level should be used as the PES for that site.

A summary of the process by which data is translated into a final geomorphological EC/PES value is shown in Figure 5.1.

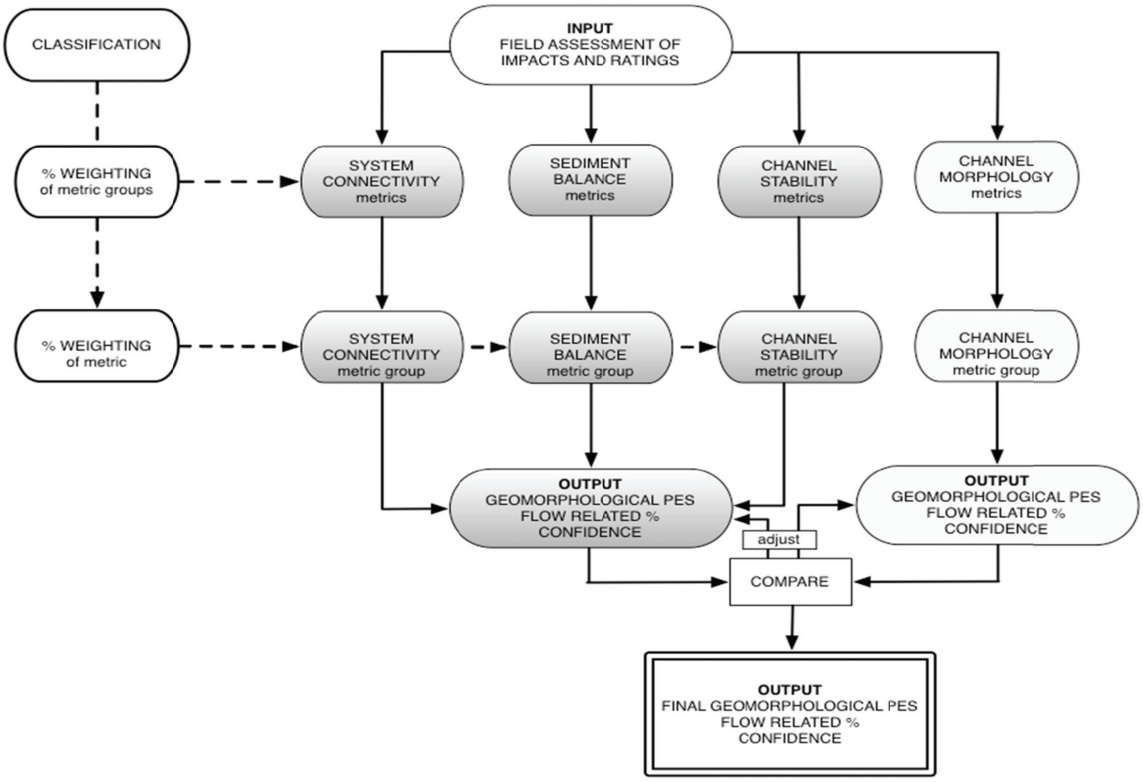

Figure 5.1 Flow diagram illustrating links between the data sheet, the metric groups and the PES

5.4 SITE SUITABILITY ASSESSMENT

The site suitability assessment is the same for both levels of the GAI. It is important to have a measure of site suitability as it gives managers an indication of the confidence with which results of the GAI can be applied to a particular river system. The site suitability table used in the GAI is presented in Table 5.1. The third criterion relates to setting flood flows in a EWR rather than determining the PES for GAI. This can be disregarded if the only purpose of the assessment is to derive the PES.

Table 5.1 Assessment of site suitability (GAI levels III and IV)

SITE SUITABILITY	COMMENT	SCORE (1-5)
How well does the morphology of the site represent that of the reach?		
To what extent is the condition of the site representative of the reach?		
Are there clear morphological features that can be related to flood levels used to determine critical flows?		
TOTAL (Sum/3)		

6 GAI: PREDICTIVE USES AND MONITORING

6.1 PREDICTING THE ECOLOGICAL CLASS UNDER DIFFERENT FLOW SCENARIOS

Previous chapters have explained how GAI can be used to assess the ecological category for the Present Ecological State, either within the River Health Programme or for setting the environmental water requirements (EWR) for the Ecological Reserve determination. Once a EWR has been set, a range of management “scenarios” are presented by which this EWR could potentially be achieved. GAI is used as one component in the Ecostatus model to predict the ecosystem response to these different flow scenarios. Rating values used in the GAI model applied to the PES assessment are adjusted to reflect a particular hypothetical management decision. It can then be gauged what impact this decision might have on the geomorphology and geohabitat of that site.

As when applying GAI to the PES, modifications to the channel in response to a flow scenario are assessed against the reference condition. Weightings for the different metrics and metric groups are kept constant.

An example of such a scenario would be a modified flow regime as a result of a proposed dam on a previously unregulated river. This would be presumed to have a major impact on longitudinal connectivity, so this metric would be given a higher impact rating. The lateral connectivity rating might also be increased due to a probable reduction in overbank flooding. If the proposed dam operation would result in increased baseflows, or a reduction in dry season flows, the channel stability metrics could be adjusted to take account of increased marginal vegetation on inset benches and channel bars.

When GAI is used in a predictive context confidence levels are low.

Three additional worksheets are provided to be used in scenario assessment. The first, SCENARIO RATING is a direct copy of the RATING worksheet, including the rating values that have been entered for the PES assessment. These rating can now be altered taking into consideration how the scenario will affect the different impacts. The new metric ratings will be automatically transferred to the SCENARIO METRICS and SCENARIO EC worksheets. These three worksheets record the changes made and the final result for a given scenario.

If additional scenarios are to be assessed it is recommended that a copy is made of the completed spreadsheet. This should be renamed EWR site NO scenario 2.

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APPENDICES

APPENDIX A: INFORMATION AVAILABLE FROM WEB SITE – GEOMORPHOLOGICAL TOOLS FOR RIVER MANAGEMENT IN SOUTH AFRICA

An interactive web site has been set up with the aim of facilitating the application and refinement of GAI. This site can be found at http://geomorphsa.com/

The site is interactive and users are encouraged to send in comments relating to their experience of using GAI and to provide examples of its use, of different river types and so on.

The web site is structured so as to provide the following information.

The latest version of the GAI manual.

Data forms for the desktop and field study.

The GAI model (level III and IV)

Photo gallery – this will be continuously updated with new examples as they become available.

Documented examples of GAI applications

Links to useful resources.

The website also includes information relevant to the assessment of Environmental Water Requirements (or Instream Flow Assessment)

APPENDIX B: FORMS FOR DESKTOP STUDY

DESKTOP ANALYSIS

GAI III and IV

SITE IDENTIFIERS

RECORDER/ASSESSOR		DATE (field data)		
RIVER SYSTEM		MAP REFERENCE		
RIVER NAME		LATUTIDE (S)		
SITE NAME		LONGITUDE (E)		
QUATERNARY CATCHMENT		SITE ALTITUDE (masl)		
CATCHMENT AREA (km^2)		MAR (Mm^3/a)		
FLOW REGIME		perennial	intermittent	ephemeral

REACH DESCRIPTION

VALLEY CONFINEMENT	
CHANNEL PATTERN	
REACH LENGTH (km)	
REACH GRADIENT (m/m)	
RIVER ZONE	

RECORD OF AERIAL IMAGERY

Date (year and month)	Scale	Quality

TABLE OF IMPACTS

LOCATION AND TYPE OF IMPACT	NOTE HOW WIDESPREAD OR FREQUENT
Reach impacts	
weirs	
causeways	
bridges	
channel straightening	
Floodplain / channel bank impacts in	
cultivation	
vegetation removal	
alien vegetation	
rural or urban settlement	
cattle/game trampling	
Main channel impacts	
Mainstream dam	
Hillslope impacts	
Active cultivation	
Former cultivation	
livestock grazing	
alien vegetation or forestry plantations	
forest clearing	
Urban development	
Rural settlement	
dirt roads	
metalled roads	
livestock tracks	
Land drainage	
Farm dams	
Gully erosion	
Bare soil and possible sheet erosion	
Other disturbance	

Mainstream dam Name:	Capacity (Mm^3)	Date of construction	Distance upstream (km)	%MAR captured

APPENDIX C: FIELD FORMS FOR GAI LEVEL III

GEOMORPHOLOGICAL FIELD DATA SHEET GAI III

1. site identifiers (from desktop study)

RECORDER		DATE (for field data)		
RIVER SYSTEM		MAP REFERENCE		
RIVER NAME		LATITUDE (S)		
SITE NAME		LONGITUDE (E)		
QUATERNARY CATCHMENT		SITE ALTITUDE (masl)		
CATCHMENT AREA (km^2)		MAR (Mm^3/a)		
FLOW REGIME		perennial	intermittent	ephemeral

2. reach description (from desktop study)

valley confinement classes given in Figure 1, channel pattern in Figure 2

VALLEY CONFINEMENT	
CHANNEL PATTERN	
REACH LENGTH (km)	
REACH GRADIENT (m/m)	
RIVER ZONE	

3. flow conditions (at site at time of survey)

flow level		flood	spate	high base flow	low base flow	no flow
flow clarity		clear	cloudy	opaque		

4. list of photographs

Number	Description

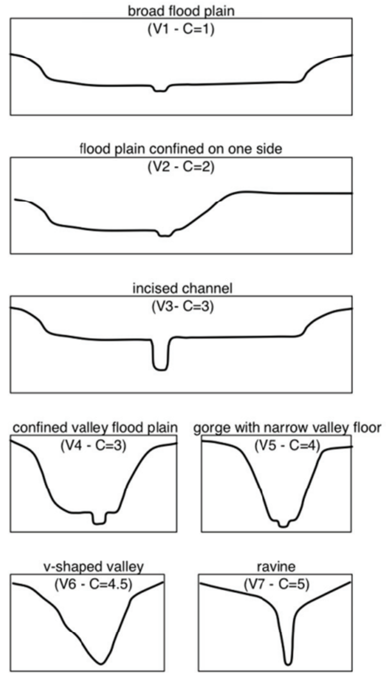

Figure 1. Valley confinement. V indicates valley type, C confinement class

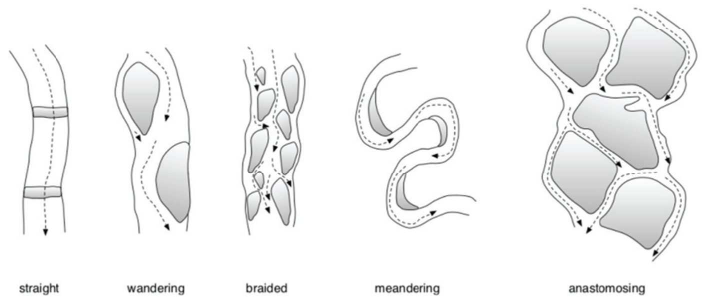

Figure 2. Classification of channel pattern

5a. sketch of channel plan view

5b. sketch of channel cross section

6. stream dimensions (assess for the site)

	Range (m)		Range (m)
Channel width		**Height of active channel bank**	
- macro-channel width		- left bank (looking downstream)	
- active channel width		- right bank	
- water surface width			

7. channel classification (assess for site)

Channel type		bedrock	mixed	alluvial	fixed boulder	
Dominant sediment	bedrock	boulder	cobble	gravel	sand	silt & clay
	Channel type					
Reach type	bedrock			mixed or alluvial		
select one according to channel type	bedrock fall	bedrock cascade	flat bedrock	pool-rapid	pool-riffle	plain bed
	pool-rapid	anastomosing/ anabranching		step-pool	flat bed	regime

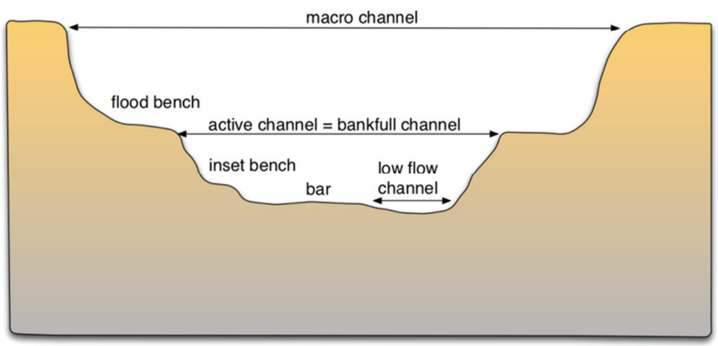

Figure 3. Definition of channel features

8. morphological units (assess for site)

bedrock		tick
in-channel features	waterfall	
	rock steps	
	rapid	
	bedrock pool	
	bedrock pavement	
	backwater	
	bedrock run	
bedrock island/ core bar		

riparian	
inset bench (< bankfull)	
flood bench (= bankfull, narrow)	
floodplain (= bankfull, wide)	
terrace (> bankfull)	

alluvial		tick
in-channel features	step	
	rapid	
	plane bed	
	riffle	
	run	
	shallow pool	
	deep pool	
	flat' sand bed	
	backwater	
	point bar	
	lateral bar	
alluvial bars	mid-channel bar	
	tributary bar	
	lee bar	
secondary channels		
islands (surface height = bankfull)		

9. bank conditions (assess for site)

BANK SEDIMENT	LHB (tick)	RHB (tick)	**BANK SLOPE**	LHB (tick)	RHB (tick)
Sand /gravel			steep > 45°		
mixed e.g cobble in sandy matrix			moderate 20-45°		
silt/clay			gentle < 20°		
weathered bedrock					
cohesive bedrock					

10. riparian vegetation (assess for site)

Describe the dominant vegetation type on each morphological feature (Fig. 3 & 4) according to the vegetation list

Morphol. Unit	Dominant Vegetation	Vegetation list
bars		bare
inset bench		annual grass and forbs
flood bench		perennial grass
floodplain		sedges and reeds
terrace		shallow rooted woody shrubs and trees
		deep rooted woody shrubs and trees

11. habitat survey (at site) - fish and invertebrates

PREVALENCE OF IN-CHANNEL HABITATS							
Indicate distribution as per scoring guidelines and dominant substrate							
Scoring	widespread . 49%	3	Frequent (10-49%	2	Infrequent (<10%	1	
Substrate	sand/silt/mud	S	gravel	G	cobble/ boulder	C	
		pool	isolated pool	glide or run	broken water		
very shallow *(< ankle - 15 cm)*							
shallow *(< knee - 50 cm)*							
deep							

HABITAT COVER PREVALENCE			
open interstitial spaces between coarse gravel or cobble		**Scoring Guideline**	
overhanging vegetation		Widespread (>49%)	3
marginal vegetation		Frequent (10-49%)	2
instream vegetation		Infrequent (<10%)	1
undercut banks			
snags (eg. woody debris)			

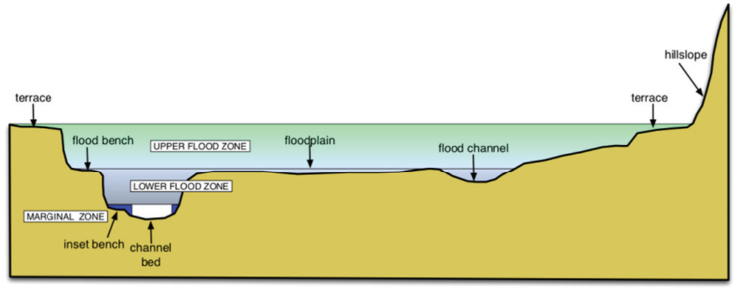

Figure 4. Channel cross-section features and vegetation zones

(a) bank related fish habitat

(b) bed related fish & invertebrate habitat

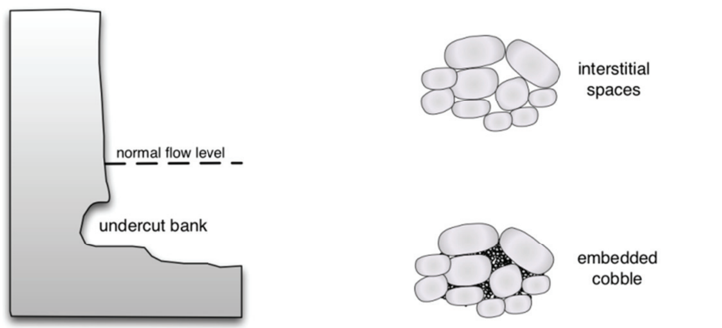

Figure 5. Habitat features related to fish cover and invertebrate habitat

12. Assessment of driver impacts (assess for reach)

TABLE 1. KNOWLEDGE OF RIVER SYSTEM
This information will help assessment of confidence scores

criteria	tick one	comment
familiar with river system through regular field visits & background research		
limited knowledge of river system		
first visit to the river system and site, limited background research		

TABLE 2. GUIDELINES FOR ASSESSING EXTENT AND INTENSITY OF IMPACT

	widespread	frequent	localized	absent	
area or length affected	>50%	10-50%	1-<10%	0%	NB absent may also include 'not observed'
severity of modification from reference					
extreme	5	3	2	0	
serious	4	2.5	1.5		
large	3	2	1	0	
moderate	2	1	0.5		
small	1	0.5	0	0	

These values are to be used as a guide to rating impacts; adjust up or down according to expert judgement.

NB. ALL CHANGES MUST BE ASSESSED IN TERMS OF HUMAN IMPACT, NOT NATURAL CHANGES eg. DUE TO LONG TERM CLIMATE CHANGE, SHORT TERM HYDROLOGICAL CHANGE (EXTREME FLOOD EVENTS) OR INTRINSIC GEOMORPHOLOGICAL CHANGE.

These guidelines should be applied to all impact assessments on pages 9-12 and 15-16.

Procedure:

1. For each criteria rate the impact according to the guidelines given in Table 2, taking into account both severity and distribution. Impacts close to the site or reach should have a higher impact rating than impacts further away. Note than a rating greater than 3 implies a severe modification of habitat.
2. The rating for the metric should be based initially on the three highest impact ratings. Table 3 provides guidelines form combining impact ratings in order to get the final metric rating. Use expert judgement to arrive at the final score.

TABLE 3. COMBINING IMPACT RATINGS TO ASSESS THE FINAL METRIC RATING

Combination of values for separate impacts	Final rating	Combination of values for separate impacts	Final rating	Combination of values for separate impacts	Final rating
1 1 1	1	3 3 3	4	4 3 2	4.5
2 1 1	2	4 1 1	4	4 3 3	4.5
2 2 1	2.5	4 2 1	4	4 4 1	4.5
2 2 2	3	4 2 2	4	4 4 2	4.5
3 1 1	3	4 3 1	4	4 4 3	5
3 3 1	3.5			4 4 4	5
3 3 2	3.5			5 1 1	5

IMPACT ON CONNECTIVITY

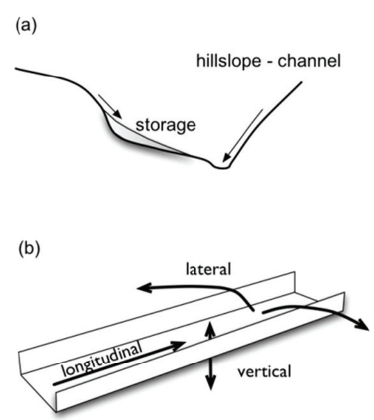

Figure 6. Connectivity in river systems (a) hillslope-channel (b) channel

Add comments here explaining how you came to your decisions regarding changes to connectivity.

IMPACT ON LONGITUDINAL CONNECTIVITY - UPSTREAM-DOWNSTREAM

Decrease in longitudinal connectivity

Is there an upstream dam with a large capacity to store water and trap sediment?
If information is available compare the reservoir capacity to the mean annual runoff (MAR). If reservoir capacity > MAR at the dam site the rating should be 3 of greater.
Consider the location of the dam relative to downstream tributaries. If significant tributaries enter main channel between study reach and the dam decrease the rating.

	capacity (Mm^3)	% MAR	distance upstream (km)	date of construction
Mainstream dam(s)				

Within reach connectivity: Are there weirs or causeways upstream that are large enough to prevent downstream movement of water and sediment?

Impact	widespread	frequent	localized	absent
Weirs (serious impact)				
Causeways (moderate impact)				
Bridges (small impact)				

Increases in longitudinal connectivity

	Flow increase relative to baseflow (impact rating)			
Is there an interbasin transfer scheme upstream of the site that significantly increases the flow in the channel?	>300% (4-5)	150-300% (3)	50-149% (2)	< 50% (1)

	widespread	frequent	localized	absent
Has there been a breach of any upstream dam or weir?				
Has any length of channel been straightened through engineering activities?				

Given the above, to what extent do you think that longitudinal connectivity has changed? (-5 to +5)	
Degree to which this change is the result of changed flow? (0-100%)	
Confidence in assessment (1-5)	

IMPACT ON LATERAL CONNECTIVITY (CHANNEL-FLOODPLAIN)

Have there been any human induced changes that have affected the connectivity between the channel and the floodplain?

criteria	widespread/ severe	frequent/ large	localized/ small	absent
Has lateral connectivity been decreased due to:				
channel incision resulting in a depth great enough to prevent normal floods reaching the upper riparian zone.				
flood protection by berms or levees				
decreased magnitude of annual floods				
Has lateral connectivity been increased due to:				
bed raised due to sediment deposition				
increased magnitude of annual floods				

Given the above, to what extent do you think that lateral connectivity has changed? (-5 to +5)	
Degree to which this change is the result of changed flow? (0-100%)	
Confidence in assessment (1-5)	

Given the above, to what extent do you think that vertical connectivity has changed? (-5 to +5)	
Degree to which this change is the result of changed flow? (0-100%)	
Confidence in assessment (1-5)	

IMPACT ON SEDIMENT SUPPLY

- Sheet erosion that is widespread over the catchment surface may be a greater sediment source than the more obvious gullies (which will increase connectivity)
- Erosion sources close to the reach should be rated higher than sources further away.
- Erosion will normally decrease over time, so erosion sites that have been active for over twenty years may be stabilizing.

hillslope erosion associated with:	wide-spread	frequent	localized	absent
Increase in sediment supply due to				
gully erosion				
cultivation				
livestock grazing				
alien vegetation or forestry				
dirt roads				
change in fire frequency				
Other				
Decrease in sediment supply due to:				
increased catchment vegetation cover				
soil conservation works				
Given the above, to what extent do you think that sediment supply has changed from reference? (-5 to +5)				
Degree to which this change is the result of changed flow? (0-100%)				
Confidence in assessment (1-5)				
bank erosion associated with				
Increase in sediment supply due to				
vegetation removal				
alien vegetation				
livestock/game trampling				
Other				
Decrease in sediment supply due to:				
active bank stabilization				
Given the above, to what extent do you think that sediment supply has changed from reference? (-5 to +5)				
Degree to which this change is the result of changed flow? (0-100%)				
Confidence in assessment (1-5)				
Channel mining (decreased supply)				
Given the above, to what extent do you think that sediment supply has changed? (-5 to +5)				
Degree to which this change is the result of changed flow? (0-100%)				
Confidence in assessment (1-5)				

Add comments here explaining how you came to your decision regarding changes to sediment supply.

IMPACT ON BED, BANK AND FLOOD ZONE STABILITY

Introduction of gabion structures or concrete or stone lining should be given the maximum rating.
The effectiveness of vegetation cover increases according to:

- vegetation type in the order: annual grasses & forbs, perennial grass, shallow rooted trees & shrubs, deep rooted trees & shrubs.
- cohesion of bank sediments in the order: bedrock, silt-clay, mixed colluvium, sand and gravel.
- angle of the bank in the order: low gradient (<20°) moderate gradient (20-45°), steep gradient (> 45°)

Impacts affecting stability of channel bed and bars				
criteria	widespread	frequent	localized	absent
Has there been a decreased in stability due to:				
loss of vegetation on bars due to livestock grazing				
Has there been an increase in stability due to:				
Increased vegetation on bars due human-induced increase in water availability or nutrient status				
Increased cover due to invasive alien vegetation				
Bed stabilization structures eg. gabions, concrete or stone lining				
Given the above, to what extent do you think that bed and bar stability has changed? (-5 to +5)				
Degree to which this change is the result of changed flow? (0-100%)				
Confidence in assessment (1-5)				

Impacts affecting stability of channel banks and riparian zone				
	widespread	frequent	localized	absent
Has there been a decrease in stability due to:				
Vegetation clearance (e.g clear cutting, firewood harvesting)				
Livestock grazing				
Loss of ground cover under alien vegetation				
Increased fire frequency				
Cultivation on floodplain				
Has there been an increase in stability due to:				
Increase in lower bank vegetation due human-induced increase in water availability or nutrient status				
Increased overhead cover due to invasive alien vegetation				
Reduced fire frequency				
Bank stabilization structures eg. gabions, concrete or stone lining				

Given the above, to what extent do you think that bank stability has changed? (-5 to +5)	
Degree to which this change is the result of changed flow? (0-100%)	
Confidence in assessment (1-5)	

Add comments here explaining how you came to your decision regarding changes to channel stability.

13. Present channel condition

Describe the current condition of the channel irrespective of cause. Use Tables 2 to rate the extent and degree of each condition.

Condition of habitat due to sediment composition and structure.	
EXAMPLE OF HABITAT CONDITION	Extent & degree
Instream	
Is there evidence of infilling of open gravel or cobble with sand or silt?	
Are there sand or silt deposits covering coarse gravel or cobble?	
If the bed consists of coarse gravel or cobble, is the bed imbricated and stable or loose and free to move? Assess extent of loose material.	
What is the extent of exposed bedrock?	
Riparian	
Is there evidence of recent sediment deposition on flood zones and channel banks?	

Condition of habitat due to sediment composition and structure.	
EXAMPLE OF HABITAT CONDITION	Extent & degree
Instream	
Is there evidence of infilling of open gravel or cobble with sand or silt?	
Are there sand or silt deposits covering coarse gravel or cobble?	
If the bed consists of coarse gravel or cobble, is the bed imbricated and stable or loose and free to move? Assess extent of loose material.	
What is the extent of exposed bedrock?	
Riparian	
Is there evidence of recent sediment deposition on flood zones and channel banks?	

Add comments here explaining how you came to your decision regarding present channel condition.

14. Morphological change

Assess the impact of human activity on geohabitat condition. Use Table 2 to rate the extent and degree of each condition. The cause should indicate evidence of human impact.

Instream changes	Extent & degree of impact	Cause
Impacts on habitat due to changes in sediment composition and structure. Time scale of multiple events.		
Loss of open gravel or cobble due to infilling with sand or silt; silt would have the most negative impact.		
Blanket covering of coarse gravel and cobble by sand or silt.		
Loss of bed imbrication in coarse gravel and cobble beds causing the bed to become more mobile.		
Stripping of sediment to expose bedrock.		
Impact on habitat due to channel geometry changes. Time scale of decades.		
Loss or gain of instream habitat due to change in channel width?		
Change in response of flow depth and velocity to discharge because of a change in width-depth ratio?		
Change in the spatial pattern of velocity-depth flow types due to increase or decrease of sand, gravel or cobble bars?		
Loss or gain of secondary channels that provide refuge during floods and habitat variability at low flow?		
Shift in composition of deposited sediment from sand to silt or vice-versa.		
Increase or decrease in rate of sediment deposition on flood prone areas.		

Given the above, to what extent do you think that instream habitat has changed as a result of changes to sediment composition and channel geometry (1-5)	
Degree to which this change is the result of changed flow? (0-100%)	
Confidence in assessment (1-5)	

Add comments here explaining how you came to your decision regarding changes to instream channel morphology.

Riparian zone changes	Extent & degree of impact	Cause
Impacts on habitat due to changes in sediment composition and structure. These changes may be evident on the time scale of multiple events.		
Shift in composition of deposited sediment from sand to silt or vice-versa.		
Increase or decrease in rate of sediment deposition on flood prone areas.		
Impact on habitat due to channel geometry changes. These changes should be evident over a time scale of decades.		
Loss or gain of riparian habitat linked to inset benches?		
Undercutting and steepening of the bank slope, or reduction in bank slope.		
Reduction in width of flood benches in the lower vegetation zone by lateral erosion.		
Gain or loss of floodplain features such as meander cutoffs.		

Given the above, to what extent do you think that riparian zone habitat has changed as a result of changes to sediment composition and channel geometry (1-5)	
Degree to which this change is the result of changed flow? (0-100%)	
Confidence in assessment (1-5)	

Add comments here explaining how you came to your decision regarding riparian zone channel morphology.

APPENDIX D: FIELD FORMS FOR GAI LEVEL IV

GEOMORPHOLOGICAL FIELD DATA SHEET GAI IV

1. site identifiers (from desktop study)

RECORDER		DATE (for field data)		
RIVER SYSTEM		MAP REFERENCE		
RIVER NAME		LATITUDE (S)		
SITE NAME		LONGITUDE (E)		
QUATERNARY CATCHMENT		SITE ALTITUDE (masl)		
CATCHMENT AREA (km^2)		MAR (Mm^3/a)		
FLOW REGIME		perennial	intermittent	ephemeral

2. reach description (from desktop study)

valley confinement classes given in Figure 1, channel pattern in Figure 2

VALLEY CONFINEMENT	
CHANNEL PATTERN	
REACH LENGTH (km)	
REACH GRADIENT (m/m)	
RIVER ZONE	

3. flow conditions (at site at time of survey)

flow level		flood	spate	high base flow	low base flow	no flow
flow clarity		clear	cloudy	opaque		

4. list of photographs

Number	Description

GAI Module B: GAI level IV Field Form

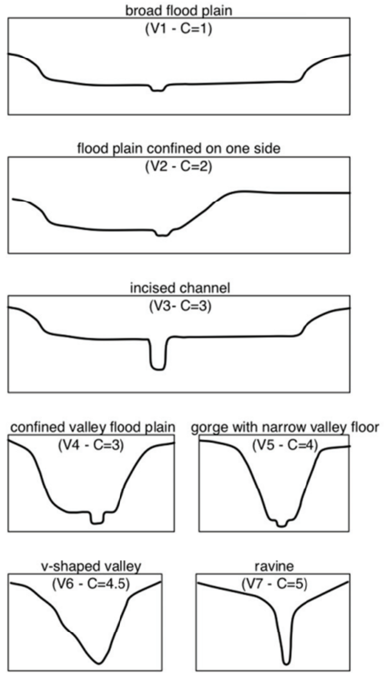

Figure 1. Valley confinement. V indicates valley type, C confinement class

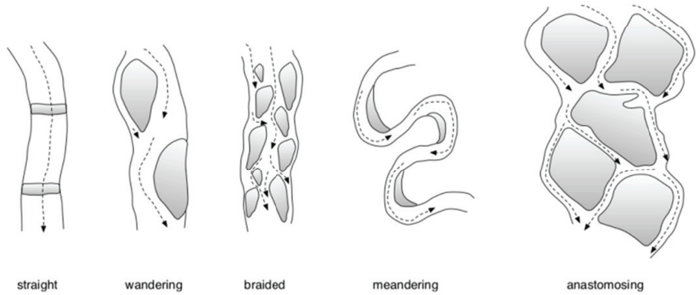

Figure 2. Classification of channel pattern

GAI Module B: GAI level IV Field Form

5a. sketch of channel plan view

5b. sketch of channel cross section

6. stream dimensions (assess for the site)

	Range (m)		Range (m)
Channel width		**Height of active channel bank**	
- macro-channel width		- left bank (looking downstream)	
- active channel width		- right bank	
- water surface width			

7. channel classification (assess for site)

Channel type			bedrock	mixed	alluvial	fixed boulder	
Dominant sediment		bedrock	boulder	cobble	gravel	sand	silt & clay
		Channel type					
Reach type		bedrock			mixed or alluvial		
select one according to channel type		bedrock fall	bedrock cascade	flat bedrock	pool-rapid	pool-riffle	plain bed
		pool-rapid	anastomosing/ anabranching		step-pool	flat bed	regime

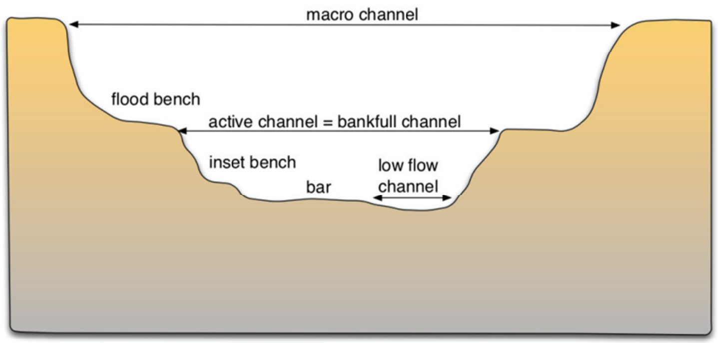

Figure 3. Definition of channel features

6. stream dimensions (assess for the site)

	Range (m)		Range (m)
Channel width		**Height of active channel bank**	
- macro-channel width		- left bank (looking downstream)	
- active channel width		- right bank	
- water surface width			

7. channel classification (assess for site)

Channel type			bedrock	mixed	alluvial	fixed boulder	
Dominant sediment		bedrock	boulder	cobble	gravel	sand	silt & clay
		Channel type					
Reach type		bedrock			mixed or alluvial		
select one according to channel type		bedrock fall	bedrock cascade	flat bedrock	pool-rapid	pool-riffle	plain bed
		pool-rapid	anastomosing/ anabranching		step-pool	flat bed	regime

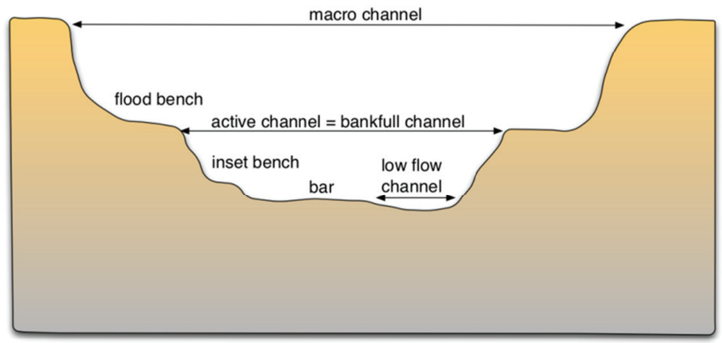

Figure 3. Definition of channel features

GAI Module B: GAI level IV Field Form

10. riparian vegetation (assess for site)

Describe the dominant vegetation type on each morphological feature (Fig. 3 & 4) according to the vegetation list

Morphol. Unit	Dominant Vegetation	Vegetation list
bars		bare
inset bench		annual grass and forbs
flood bench		perennial grass
floodplain		sedges and reeds
terrace		shallow rooted woody shrubs and trees
		deep rooted woody shrubs and trees

11. habitat survey (at site) - fish and invertebrates

PREVALENCE OF IN-CHANNEL HABITATS						
Indicate distribution as per scoring guidelines and dominant substrate						
Scoring	widespread . 49%	3	Frequent (10-49%	2	Infrequent (<10%	1
Substrate	sand/silt/mud	S	gravel	G	cobble/ boulder	C
		pool	isolated pool	glide or run	broken water	
very shallow *(< ankle - 15 cm)*						
shallow *(< knee - 50 cm)*						
deep						

HABITAT COVER PREVALENCE		
open interstitial spaces between coarse gravel or cobble		**Scoring Guideline**
overhanging vegetation		Widespread (>49%) 3
marginal vegetation		Frequent (10-49%) 2
instream vegetation		Infrequent (<10%) 1
undercut banks		
snags (eg. woody debris)		

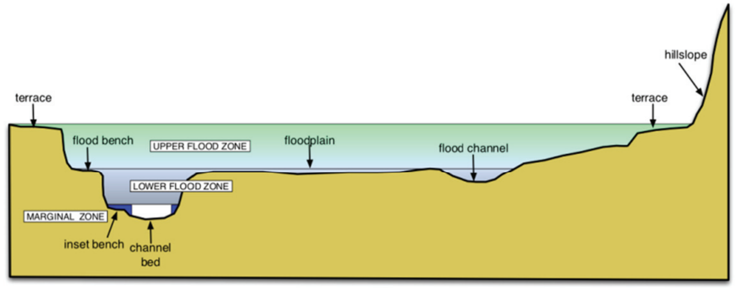

Figure 4. Channel cross-section features and vegetation zones

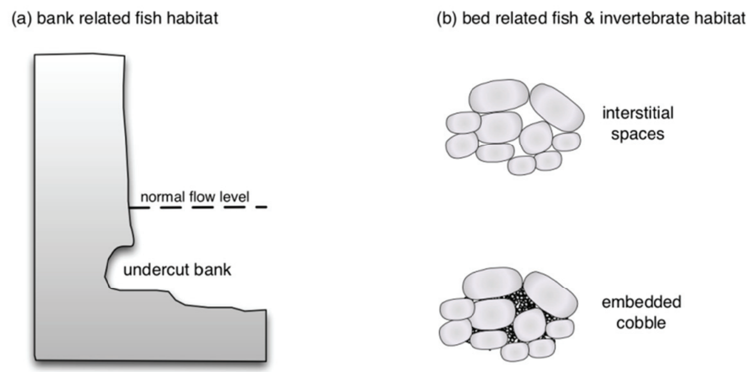

Figure 5. Habitat features related to fish cover and invertebrate habitat

12. Assessment of driver impacts (assess for reach)

TABLE 1. KNOWLEDGE OF RIVER SYSTEM
This information will help assessment of confidence scores

criteria	tick one	comment
familiar with river system through regular field visits & background research		
limited knowledge of river system		
first visit to the river system and site, limited background research		

TABLE 2. GUIDELINES FOR ASSESSING EXTENT AND INTENSITY OF IMPACT

	widespread	frequent	localized	absent
area or length affected	>50%	10-50%	1-<10%	0%
severity of modification from reference				
extreme	5	3	2	0
serious	4	2.5	1.5	
large	3	2	1	0
moderate	2	1	0.5	
small	1	0.5	0	0

NB absent may also include 'not observed'

These values are to be used as a guide to rating impacts; adjust up or down according to expert judgement.

NB. ALL CHANGES MUST BE ASSESSED IN TERMS OF HUMAN IMPACT, NOT NATURAL CHANGES eg. DUE TO LONG TERM CLIMATE CHANGE, SHORT TERM HYDROLOGICAL CHANGE (EXTREME FLOOD EVENTS) OR INTRINSIC GEOMORPHOLOGICAL CHANGE.

These guidelines should be applied to all impact assessments on pages 9-12 and 15-16.

Procedure:
1. For each criteria rate the impact according to the guidelines given in Table 2, taking into account both severity and distribution. Impacts close to the site or reach should have a higher impact rating than impacts further away. Note than a rating greater than 3 implies a severe modification of habitat.
2. The rating for the metric should be based initially on the three highest impact ratings. Table 3 provides guidelines form combining impact ratings in order to get the final metric rating. Use expert judgement to arrive at the final score.

TABLE 3. COMBINING IMPACT RATINGS TO ASSESS THE FINAL METRIC RATING

Combination of values for separate impacts	Final rating	Combination of values for separate impacts	Final rating	Combination of values for separate impacts	Final rating
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2 2 1	2.5	4 2 1	4	4 4 1	4.5
2 2 2	3	4 2 2	4	4 4 2	4.5
3 1 1	3	4 3 1	4	4 4 3	5
3 3 1	3.5			4 4 4	5
3 3 2	3.5			5 1 1	5

IMPACT ON CONNECTIVITY

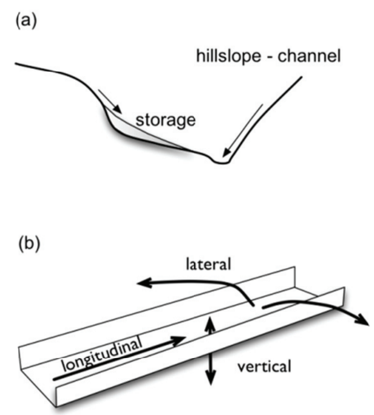

Figure 6. Connectivity in river systems (a) hillslope-channel (b) channel

Add comments here explaining how you came to your decisions regarding changes to connectivity.

IMPACT ON HILLSLOPE-CHANNEL CONNECTIVITY

These impacts affect the generation of storm runoff and the delivery of sediment to the main channel via hillslopes and low order tributaries.

criteria	widespread	frequent	localized	absent
Increased network connectivity due to:				
- gully erosion (not in wetland)				
- artificial drainage				
- road networks				
- livestock tracks				
- wetland incision (in catchment)				
- incision of alluvial fans				
Increased runoff potential due to:				
- bare ground				
- compaction (livestock or farm traffic)				
- urban development				
Increased storage due to:				
- farm dams				
structural interventions on alluvial fans				
Other				

Given the above, to what extent do you think that hillslope-channel connectivity has changed? (-5 to +5)	
Degree to which this change is the result of changed flow? (0-100%)	
Confidence in assessment (1-5)	

IMPACT ON LONGITUDINAL CONNECTIVITY - UPSTREAM-DOWNSTREAM

Decrease in longitudinal connectivity

Is there an upstream dam with a large capacity to store water and trap sediment?
If information is available compare the reservoir capacity to the mean annual runoff (MAR). If reservoir capacity > MAR at the dam site the rating should be 3 of greater.
Consider the location of the dam relative to downstream tributaries. If significant tributaries enter main channel between study reach and the dam decrease the rating.

	capacity (Mm^3)	% MAR	distance upstream (km)	date of construction
Mainstream dam(s)				

Within reach connectivity: Are there weirs or causeways upstream that are large enough to prevent downstream movement of water and sediment?

Impact	widespread	frequent	localized	absent
Weirs (serious impact)				
Causeways (moderate impact)				
Bridges (small impact)				

Increases in longitudinal connectivity

	Flow increase relative to baseflow (impact rating)			
Is there an interbasin transfer scheme upstream of the site that significantly increases the flow in the channel?	>300% (4-5)	150-300% (3)	50-149% (2)	< 50% (1)
	widespread	frequent	localized	absent
Has there been a breach of any upstream dam or weir?				
Has any length of channel been straightened through engineering activities?				

Given the above, to what extent do you think that longitudinal connectivity has changed? (-5 to +5)	
Degree to which this change is the result of changed flow? (0-100%)	
Confidence in assessment (1-5)	

IMPACT ON LATERAL CONNECTIVITY (CHANNEL-FLOODPLAIN)

Have there been any human induced changes that have affected the connectivity between the channel and the floodplain?				
criteria	widespread/ severe	frequent/ large	localized/ small	absent
Has lateral connectivity been **decreased** due to:				
channel incision resulting in a depth great enough to prevent normal floods reaching the upper riparian zone.				
flood protection by berms or levees				
decreased magnitude of annual floods				
Has lateral connectivity been **increased** due to:				
bed raised due to sediment deposition				
increased magnitude of annual floods				

Given the above, to what extent do you think that lateral connectivity has changed? (-5 to +5)	
Degree to which this change is the result of changed flow? (0-100%)	
Confidence in assessment (1-5)	

IMPACT ON VERTICAL CONNECTIVITY

Only rate impacts that are clearly related to human activity. Remember that the condition of sediment on the channel bed is closely related to the last flood event and can change significantly due to natural geomorphic variability.

criteria	widespread	frequent	localized	absent
sediment deposition (increase)				
sediment stripping (decrease)				
infilling with fines (decrease)				
bed hardening (decrease)				

Given the above, to what extent do you think that vertical connectivity has changed? (-5 to +5)	
Degree to which this change is the result of changed flow? (0-100%)	
Confidence in assessment (1-5)	

IMPACT ON SEDIMENT SUPPLY

- Sheet erosion that is widespread over the catchment surface may be a greater sediment source than the more obvious gullies (which will increase connectivity)
- Erosion sources close to the reach should be rated higher than sources further away.
- Erosion will normally decrease over time, so erosion sites that have been active for over twenty years may be stabilizing.

hillslope erosion associated with:	wide-spread	frequent	localized	absent
Increase in sediment supply due to				
gully erosion				
cultivation				
livestock grazing				
alien vegetation or forestry				
dirt roads				
change in fire frequency				
Other				
Decrease in sediment supply due to:				
increased catchment vegetation cover				
soil conservation works				
Given the above, to what extent do you think that sediment supply has changed from reference? (-5 to +5)				
Degree to which this change is the result of changed flow? (0-100%)				
Confidence in assessment (1-5)				
bank erosion associated with				
Increase in sediment supply due to				
vegetation removal				
alien vegetation				
livestock/game trampling				
Other				
Decrease in sediment supply due to:				
active bank stabilization				
Given the above, to what extent do you think that sediment supply has changed from reference? (-5 to +5)				
Degree to which this change is the result of changed flow? (0-100%)				
Confidence in assessment (1-5)				
Channel mining (decreased supply)				
Given the above, to what extent do you think that sediment supply has changed? (-5 to +5)				
Degree to which this change is the result of changed flow? (0-100%)				
Confidence in assessment (1-5)				

Add comments here explaining how you came to your decision regarding changes to sediment supply.

IMPACT ON BED, BANK AND FLOOD ZONE STABILITY

Introduction of gabion structures or concrete or stone lining should be given the maximum rating.
The effectiveness of vegetation cover increases according to:

- vegetation type in the order: annual grasses & forbs, perennial grass, shallow rooted trees & shrubs, deep rooted trees & shrubs.
- cohesion of bank sediments in the order: bedrock, silt-clay, mixed colluvium, sand and gravel.
- angle of the bank in the order: low gradient (<20°) moderate gradient (20-45°), steep gradient (> 45°)

Impacts affecting stability of channel bed and bars				
criteria	widespread	frequent	localized	absent
Has there been a decreased in stability due to:				
loss of vegetation on bars due to livestock grazing				
Has there been an increase in stability due to:				
Increased vegetation on bars due human-induced increase in water availability or nutrient status				
Increased cover due to invasive alien vegetation				
Bed stabilization structures eg. gabions, concrete or stone lining				
Given the above, to what extent do you think that bed and bar stability has changed? (-5 to +5)				
Degree to which this change is the result of changed flow? (0-100%)				
Confidence in assessment (1-5)				

Impacts affecting stability of channel banks (impacts within 3 m of bank top)				
	widespread	frequent	localized	absent
Has there been a decrease in stability due to:				
Vegetation clearance (e.g clear cutting, firewood harvesting)				
Livestock grazing				
Loss of ground cover under alien vegetation				
Increased fire frequency				
Has there been an increase in stability due to:				
Increase in lower bank vegetation due human-induced increase in water availability or nutrient status				
Increased overhead cover due to invasive alien vegetation				
Reduced fire frequency				
Bank stabilization structures eg. gabions, concrete or stone lining				
Given the above, to what extent do you think that bank stability has changed? (-5 to +5)				
Degree to which this change is the result of changed flow? (0-100%)				
Confidence in assessment (1-5)				

Impacts affecting stability of flood zones				
	widespread	frequent	localized	absent
Has there been a decrease in stability due to:				
Vegetation clearance (e.g clear cutting, firewood harvesting)				
Livestock grazing				
Cultivation				
Loss of ground cover under alien vegetation				
Increased fire frequency				
Has there been an increase in stability due to:				
Increased overhead cover due to invasive alien vegetation				
Reduced fire frequency				
Given the above, to what extent do you think that flood zone stability has changed? (-5 to +5)				
Degree to which this change is the result of changed flow? (0-100%)				
Confidence in assessment (1-5)				

Add comments here explaining how you came to your decision regarding changes to channel stability.

13. Constructing the reference condition

Refer to Table 4 for guidelines as to characteristic channel morphology by river zone.

Describe how the channel morphology and associated habitat would change in the absence of observed changes to connectivity, sediment supply and bed and bank stability. The effect of removing impacts should normally be considered in the order indicated (1-3), taking into consideration the effect of removing the previous impact.

Zone (from page 1)		
IMPACTS TO FACTOR OUT	MORPHOLOGICAL RESPONSE METRIC	DESCRIPTION OF STATE CHANGE (CHANNEL MORPHOLOGY AND ASSOCIATED GEO-HABITAT)
1. Increased/ decreased connectivity	**Substrate changes to:**	
	– channel bed and bar	
	– channel bank and flood zone	
	Channel geometry changes to:	
	– cross pattern	
	– channel width and/or depth	
	– channel bank slope	
	– channel benches	
2. Increased/ decreased sediment supply	**Substrate changes to:**	
	– channel bed and bar	
	– channel bank and flood zone	
	Channel geometry changes to:	
	– cross pattern	
	– channel width and/or depth	
	– channel bank slope	
	– channel benches	
3. Increased/ decreased bed and bank stability	**Substrate changes to:**	
	– channel bed and bar	
	– channel bank and flood zone	
	Channel geometry changes to:	
	– cross pattern	
	– channel width and/or depth	
	– channel bank slope	
	– channel benches	

TABLE 4. CHARACTERISTIC RIVER MORPHOLOGY ACCORDING TO RIVER ZONE

Longitudinal zone	Macro-reach characteristics			Characteristic channel features
	Valley form	Gradient class	Zone class	
A. Zonation associated with a 'normal' profile				
Source zone	V1	not specified	S	Low gradient, upland plateau or upland basin able to store water. Spongy or peaty hydromorphic soils.
Mountain headwater stream	V6, V7	> 0.1	A	Very steep gradient streams 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	V6, V7	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	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	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	V4, V2	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	V1, V2 V3	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.
B. Additional zones associated with a rejuvenated profile				
Rejuvenated bedrock fall / cascades	V5	>0.02	Ar/Br/ 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	V4, V5	0.001 - 0.02	Dr/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	V1, V2, V3	< 0.005	Fr	A low gradient channel associated with high altitude plateau areas. Commonly associated with meandering channels and floodplain wetlands. Down cutting constrained by a barrier such as a dolerite dike.

Riparian zone changes	Extent & degree of impact	Cause
Impacts on habitat due to changes in sediment composition and structure. These changes may be evident on the time scale of multiple events.		
Shift in composition of deposited sediment from sand to silt or vice-versa.		
Increase or decrease in rate of sediment deposition on flood prone areas.		
Impact on habitat due to channel geometry changes. These changes should be evident over a time scale of decades.		
Loss or gain of riparian habitat linked to inset benches?		
Undercutting and steepening of the bank slope, or reduction in bank slope.		
Reduction in width of flood benches in the lower vegetation zone by lateral erosion.		
Gain or loss of floodplain features such as meander cutoffs.		

Given the above, to what extent do you think that riparian zone habitat has changed as a result of changes to sediment composition and channel geometry (1-5)	
Degree to which this change is the result of changed flow? (0-100%)	
Confidence in assessment (1-5)	

Add comments here explaining how you came to your decision regarding riparian zone channel morphology.