# Development of an Index of stream Geomorphology for the Assessment of River Health

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**Abbreviations**

RHP River Health Programme
ISC Index of Stream Condition
EMAP Environmental Monitoring and Assessment Programme

*Prepared for the River Health Programme, January 1999*

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## 1. Background and Motivation

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River channels are geomorphological features which are formed by the water and sediment that they transport. It is not surprising, therefore, that fluvial geomorphology has become an important component of many river management initiatives. The geomorphological processes determine the morphology of the channel which in turn provides the physical framework within which the stream biota live. Geomorphology is therefore an important consideration in the assessment of river health. This report describes the development of a geomorphological index to describe the condition of biomonitoring sites. Such an index is required as an input to the River Health Programme.

Geomorphology is one of several components used to assess the overall condition of a site. In the RHP seven components have been chosen: invertebrates (SASS), fish (FCII), riparian vegetation, habitat integrity, water quality, hydrology, geomorphology. Invertebrates, fish and vegetation together give a good picture of the ecological integrity of a site and reflect the condition of the bio-physical habitat which are described by the remaining components, habitat integrity, water quality, hydrology and geomorphology. Changes to the stream biota must therefore be assessed against a background of possible changes to channel morphology and channel condition. Two components of the geomorphological index have been recommended as part of a site rating and monitoring programme: firstly a channel classification and index of channel stability and secondly an index of channel condition.

A geomorphological classification of the site would serve three purposes:

to classify the channel with respect to channel type so as to allow similar sites to be grouped together;
to provide archival reference data to which later surveys can be related;
to provide data from which a geomorphological index of channel stability can be derived.

Channel change can occur for two reasons. It can occur both naturally (over short and long time periods) and as a result of anthropogenic modification to rivers or their catchments (eg. impoundments, water transfers, agriculture). A geomorphological index of channel stability is used to classify sites according to their potential for morphological change as a result of both natural and anthropogenic change. Such an index is important in interpreting biotic changes observed during the monitoring programme. It is unlikely that the site classification would change over the time span of the envisaged monitoring programme and would therefore only need to be carried out during the site rating.

The assessment of channel condition should be carried out on a regular basis as part of the long term monitoring. An index of channel condition, based on bed and bank conditions, would be coupled with a hydraulic biotope diversity index (HBDI). The HBDI describes the diversity of hydraulic habitats at a site in terms of both flow hydraulics and substrate conditions. Habitat is classified using hydraulic biotope classes which can be assessed from observations of flow type (surface flow characteristics) and substrate class, backed up by point velocity and depth measurements. Long term monitoring using the HBDI would provide a good measure of changes in habitat related for example to changes in substrate conditions or channel morphology. This index is still in its developmental stages and is not considered in this report.

A successful biomonitoring index must meet a number of criteria: it must provide a meaningful and accurate representation of the river condition, it must be based on field data that is simple to collect, it must be simple to interpret by the non-specialist manager. It is not always easy to marry the first criterion with the second two and most indices will be a compromise. Indices can also be developed at a number of levels. The manager would like a single value which can be used to flag problems, but this single index may be disaggregated into its component parts so that the cause of the problem can be pinpointed. The geomorphological index described in this report attempts to meet the above criteria.

# 2. Review of current literature

A number of previous studies have looked at geomorphological indices. The most relevant to South Africa are probably those from Australia and New Zealand where climatic conditions and the scale of both the landscape and the management problems are relatively similar. Other counties such as the British Isles and the USA or Canada may also furnish useful studies, but it must be remembered that the geomorphological driving forces in these countries are somewhat different, as are the scale of management problems.

***Australia***

One of the main projects that was drawn on for the present study was the Index of Stream Condition, developed by the Department of Natural Resources and the Environment, Melbourne (Waterway and Floodplain Unit, 1997). The purpose of this index was to benchmark the condition of streams and assess the effectiveness of long term management intervention in managing and rehabilitating streams. Unlike the RHP that uses seven indices, the Index of Stream Condition (ISC) is based on five aspects: hydrology, physical form, streamside zone, water quality and aquatic life. The geomorphology fits into the physical form component which deals with bank stability, spatial extent, width, influence of artificial barriers and abundance and origin of coarse woody debris.

The ISC attempts to look at the extent that the stream has changed from its natural or ideal conditions. It is important to adopt this concept when developing the geomorphological and other indices. This measure of change is used to flag problems as opposed to providing the detailed information that a manager or developer would need about the stream. Similar to the RHP, the developers of the ISC used sub indices for the various components. Each index is rated out of 10 and the ratings are then compiled by putting them on a bar with the maximum length of 50 units (5 categories with 10 units each). This gives a good visual display of how much each component contributes to the total index.

The developers of the ISC used a method of selecting a number of possible geomorphological variables. From this list four indicators were then chosen. The ones that were difficult to apply were generally excluded as were those that lent themselves to too much natural variation between areas even when under natural conditions. The selected indicators show change from natural conditions without being masked by the wide variability in physical form throughout the State. The indicators were bank stability, bed condition, influence of artificial barriers and the density of coarse woody debris. It was felt that the effects of channel modification were adequately assessed by measurements of bank stability and bed condition. A “rating of departures” of stream condition from naturalness is implemented on a five point scale, ranging from 0 **-** 4. Each score is given a description of what the rating should be associated with. There is also a set of photographs that accompany the descriptions. Each of the ratings were summed and multiplied by a factor that gave a value out of 10. The factor depends on whether there is coarse woody debris present or not. Four transects are evaluated at each reach and an average is worked out. It is a simple method and index that could be incorporated into the overall ISC.

When assessing the ISC, rivers are classified in three broad groups: mountain, valley and flood plain. Water quality scoring and the effect of woody debris are dependent on the type of river, but it did not appear to affect the scoring of the physical form.

**United States of America**

The United States also has a number of biomonitoring programmes. EMAP (Environmental Monitoring and Assessment Programme) looks at the annual statistics for the ecological state and trends of surface waters in the United States (Uys et al. 1996). They have divided the indicators into three fields, namely Response, Exposure/Habitat and Stressor indicators. The geomorphological components occur in each one of the fields as the Sedimentary diatom assemblage, Physical habitat structure and Flow and channel modifications respectively. They have broken the Physical habitat quality into 5 groups that include riparian vegetation, water-body size, water body persistence, habitat type and habitat complexity. The flow and channel modifications are assessed from records and habitat evaluation during annual sampling. It does not give an indication of how these annual sampling results are achieved, so does not help in this development of a geomorphological index.

EMAP also worked on the index concept which is the amalgamation of three components: Index period, Index location, Numerical indices. What is useful to remember from the index period, is that one should try and obtain data at times that are relatively stable, so likely to give the most uniform results. This is important as an index is a "snapshot" so should be most representative. The index period for lakes in northeastern US is mid- to late summer. Although this is a period of considerable natural stress, the biological communities are more stable than in other seasons.

**Britain**

In the United Kingdom and the Isle of Man a River Habitat Survey (RHS) has been developed to assess the physical character and quality of river habitats and the extent to which they are modified from natural conditions (Raven et al. 1998). The survey acknowledges that river habitat quality is linked to the physical character of the individual types of river and that it is affected by the degree of artificial modification of the channel and adjacent river corridor. The database of RHS is based on 5 600 reference sites, each 500 m in length, and represents a unique source of baseline information on the physical characteristics of rivers in the study region.

The RHS compares rivers in terms of river types which are derived retrospectively from the database. Common river types identified include steep streams, mountain valley rivers, upland plateau rivers, gorge rivers, small lowland riffle dominated rivers, large lowland rivers, clay rivers, chalk rivers, groundwater-fed sandstone rivers, inter-lake rivers, drains and dykes. They can be seen to represent a combination of the location along the river profile and the local geology.

**South Africa**

Rowntree and Wadeson (1999) developed a hierarchical geomorphological classification model that provides a scale based framework that can be applied to any river system. One aim of the model was to provide a standardised reference system and terminology to be used by all river scientists. It provides a useful framework for an exercise such as biomonitoring.

The hierarchical framework of Rowntree and Wadeson (1999) is composed of five nested levels: response zones, segments or river zones, reaches, morphological units and hydraulic biotopes. It was felt that an assessment of the change exhibited at a site could be best looked at in terms of morphological units and reaches. These were small enough to reflect the erosion/deposition features and large enough to recognise change.

The site inventory sheets developed by Rowntree and Wadeson (1999) have been used as the basis for the Geomorphological Index presented in this report.

## 3. Deriving the Geomorphological Index

The Geomorphological Index is composed of two main parts: a measure of the inherent stability of the channel based on its classification using Rowntree and Wadeson's hierarchical scheme (Rowntree and Wadeson 1999) and a measure of the observed channel condition. It thus combines the approaches of the British RHS, which emphasises the structure of the river, with that of the Australian ISC which emphasises the condition of the river. This approach facilitates the rational interpretation of observed changes. Some channels are inherently unstable and evidence of erosion or deposition represents the natural, expected condition of the channel. It would also be expected that the condition of the site would change between monitoring visits. A lowland sand bed river is a case in point. Other channels are inherently more stable so that any evidence of erosion or deposition would be cause for alarm.

It is recommended that the site geomorphology is assessed at two levels. The first is the full scale assessment by an experienced geomorphologist, this would form the base line study from which the channel classification would be derived. The second level is the routine monitoring by a trained technician. The channel condition index derived from the monitoring exercise is derived of five components: the river zone, the channel type, the extent of bank erosion, the degree of bed degradation (erosion), the degree of bed aggradation (deposition).

Experience whilst developing the index has shown that it is no easy task to assign an inherent stability to a channel. It is recommended therefore that the programme evolves in three stages:

1. A full geomorphological assessment is derived from the baseline survey. The site is allocated to a river zone and channel type.
2. An assessment of channel condition is obtained at regular intervals during routine monitoring; this data is stored on a data base.
3. Analysis of the data base to evaluate the characteristic channel condition for different river zone/type combinations.
4. Development of an Inherent Stability Index based on channel type and river zone.

**The base line survey**

Data sheets for the base line survey are given in Appendix A. The assessment should be carried out by an experienced geomorphologist.

Basic site details (Section 1) are derived from a 1: 50 000 map (river name, altitude, channel gradient, lat. long.) or from a GPS (lat. long). The channel gradient and site position along the river network is used to assign the site to a river zone according to Table 1. The data sheets contain six further sections to be completed at the site.

The choice of site will depend in part on criteria required by the other specialist fields, but the site should be representative of the geomorphology of the channel reach. The extent of the site for assessment of the geomorphology should include the hydraulic control (riffle, rapid etc.) and the upstream and downstream morphological features (usually pools). The whole length should be visible at one location. When filling in the data sheets the observer should take cognisance of the full active channel characteristics (and macro-channel where relevant), not just the channel area presently occupied by flow.

Photographs should be taken to record the characteristics of the site (Section 2). In particular every attempt should be made to take a good overhead shot to show the plan view of the site. Shots looking up and down stream should include the river banks.

Section 3 relates to the condition of the local catchment and allows the observer to judge the extent to which the channel is likely to have been modified from natural conditions. The degree of the effect should be rated in terms of the extent to which it is likely to have impacted on geomorphological processes. This would normally have been effected through a change in the flood regime or the supply of sediment to the channel.

Section 4 require the observer to make a sketch of the channel plan and channel cross section across a hydraulic control (normally a riffle or rapid) and a pool. A cross-section template is provided to assist the observer in identifying the main channel features. A good sketch map and cross-sections are invaluable when assessing change at some future date. Once available, the site photographs can be used to tidy up the field sketches. The channel dimensions should be recorded in the appropriate table.

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

| ***Geomorphol-ogical zone*** | ***Characteristic gradient*** | ***Diagnostic Channel Characteristics*** |
|---|---|---|

| A. *Zonation associated with a 'normal' profile* | | |
|---|---|---|
| ***1. Source zone*** | not specified | Low gradient, upland plateau or upland basin able to store water. Spongy or peaty hydromorphic soils. |
| ***2. Mountain headwater stream*** | ***0.1 - 0.7*** | ***A very steep gradient stream dominated by vertical flow over bedrock with waterfalls and plunge pools. Normally first or second order. Reach types include bedrock fall and cascades.*** |
| ***3. Mountain stream*** | 0.01 - 0.1 | Steep gradient stream dominated by bedrock and boulders, locally cobble or coarse gravels in pools. Reach types include cascades, bedrock fall, step-pool, plane bed, pool-rapid or pool riffle. Approximate equal distribution of 'vertical' and 'horizontal' flow components. |
| ***4. Foothills (cobble bed)*** | 0.005 - 0.01 | Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plane 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. |
| ***5. Foothills (gravel bed)*** | 0.001 - 0.005 | 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. |
| ***6. Lowland sand bed or Lowland floodplain*** | 0.0001- 0.001 | Low gradient alluvial sand bed channel, typically regime reach type. Often 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*** | | |
| ***7. Rejuvenated bedrock fall / cascades*** | 0.01 - 0.5 | Moderate to steep gradient, often 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. |
| ***8. Rejuvenated foothills*** | 0.001 - 0.01 | 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 flood plain may be present between the active and macro-channel. |
| 9. ***Upland flood plain*** | 9.0.0001- 0.001 | 9.An upland low gradient channel, often associated with uplifted plateau areas as occur beneath the eastern escarpment. |

9.

Section 5 relates to the riparian and in-channel vegetation. Vegetation is an important variable controlling channel stability and sediment deposition so that it is important to have information on its condition. Encroachment of vegetation on to channel bars is a good indication of long term channel change, or channel recovery from a major flood.

Section 6 relates to the morphology of the channel at a range of scales. Descriptions of the different categories are provided in the Guidelines for Site Assessment (Appendix B). Time should be spent making a careful survey of the bed material within the separate morphological units representing the hydraulic control, the pool and any bar features as it is the bed material which is most sensitive to change. The channel morphology should be used to check the zone classification as given in Table 1.

The data collected through the base line survey is used to classify the channel with regards to the river zone and channel type. The data sheets for the base line survey must be filed for future reference. They provide a detailed assessment against which future change can be assessed. They also provide basic data to aid the interpretation of the results of regular monitoring.

**Site monitoring**

Site monitoring is carried out at regular intervals (including the baseline survey) to assess the condition of the channel with respect to banks and channel bed. The assessment sheets are designed to be filled in by a trained technician. The observer should carry a set of photographs taken during the base line survey so that any changes to the channel morphology can be picked up. He/she should be encouraged to move around the site, to visit both sides of the channel and to examine the condition of the bed in both pools and hydraulic controls. A reliable assessment cannot be made from one point on the river bank.

The background site data (lat. long., altitude etc.)(Section 1) should be available from the baseline survey. The sketch map should be used to indicate changes that are evident from a comparison with the baseline photographs. A new set of comparable photographs should be taken.

Section 2 requests information on the flow conditions at the time of the survey. This aids the interpretation of the results. For example on the one hand if the river was in high flow with opaque water it would be more difficult to make the assessment of channel condition as many of the features would be obscured and many parts of the channel would be inaccessible. On the other hand, during no or very low flows it can be difficult to interpret the channel morphology. The most reliable assessment is probably made under moderate flow conditions with clear water when the morphological features are most clearly defined, but the bed is accessible for assessment.

A summary of the condition of the bank vegetation is obtained from Section 3, whilst channel modifications and bank impacts are recorded in Section 4. These two sections are not used directly to derive the condition score, but can be used to monitor conditions and explain the scores obtained.

An assessment of channel condition is carried out using Section 5. The banks, bars and bed are assessed separately. This information is used to derive the score under Section 6 (General Assessment). The ratings are derived from those given by the Waterway and Floodplain Unit (1997) adapted for South African conditions.

The separate scores for the bank, bed degradation and bed aggradation are transferred to the rating table on the first page. This table also includes a score for the river zone (1 - 9, Table 1) and the channel type (1 - 4, Table 2).

An example of a score would be as follows. A score of 43402 would indicate a foothills cobble bed river, alluvial channel type, with extreme bank erosion, no bed degradation and moderate bed aggradation. The rating points to a disturbed condition for such a river zone/channel type combination. A score of 73202 would indicate an upland flood plain river (hence meandering), alluvial channel type with moderate bank erosion and bed aggradation. Such a rating points to a channel undergoing bank erosion and redeposition of sediments in response to the natural migration of a meandering channel across its floodplain.

These five component scores must be stored in a data base for future analysis of characteristic channel condition.

Table 2. Channel Types

| | |
|---|---|
| 1. Bedrock channels | Formed where the energy of the stream during flood events is sufficient to transport all available loose material, whether it is coming in from the side slopes, the banks or the bed of the stream itself. In bedrock channels the geology of the channel bed and its resistance to erosion is the main determinant of channel form. |
| 2.Fixed boulder bed channel | Bed morphology dominated by large boulders which are in excess of the competence of all but extreme flood events. Source of boulders often direct input from valley side slopes. May be a palaeo feature. |

| | |
|---|---|
| 3. Alluvial channels | Formed within the sediment which is being transported by the river. Both the bed and the banks of the river are composed of sediment which is in temporary storage within the system. The channel form is the result of the balance between the available sediment and the transport capacity of the flow. They have a relatively rapid morphological response to changes in discharge as alluvial channels will tend towards a graded form in equilibrium with the flow regime and sediment calibre. |
| 4.Mixed channels | 1.Alternating bedrock (or fixed boulder bed) and alluvial sections. |

1.

## *4. Testing*

The Geomorphological Index was developed and tested using as wide a range of rivers as possible given the time constraints for the project. A number of rivers in the Eastern Cape were chosen, a few sites in the Western Cape and Kwa-Zulu Natal were also evaluated. The rivers were:

Eastern Cape Bloukrans, Palmiet, Keiskamma, Kat, Fish, Kap, Kowie, Kariega, Skoenmakers

Western Cape Windows, Disa, Newlands, Cecelia,

Kwa-Zulu Natal Mkomazi.

Initial testing was carried out by Ms Gina Ziervogel in conjunction with a number of student assistants (Environmental Science Honours students) who had limited training in the field. Experts in the zoological and ecological reserve fields, Prof Jay O'Keeffe and Dr Heather MacKay respectively, also helped undertake field assessments and critically assessed the index that was calculated. The index as finally proposed by Ziervogel was further tested by Ms Emily Cobbern as part of her Geography Honours project (Cobbern 1998). Finally it was applied to the Mkomazi River during the Honours Fluvial Geomorphology field trip under the guidance of Prof Kate Rowntree. The data sheets have also been made available to Mr Nigel Kemper and Ms Helen Dallas for use at biomonitoring sites in Mpumalanga.

A number of problems became apparent throughout the trials.

1 Classification of geomorphological features requires a considerable level of experience. Most evaluators found it difficult to relate the features to the descriptions given in the field manual. More visual material in the form of diagrams and photographs is needed, plus field training.

2 Assessment of stream condition involves a significant degree of subjectivity which, again, requires experience of a wide range of conditions. Groups of students using an earlier edition of the data sheets came up with a significant range of results for one site. Despite attempts to reduce the amount of subjectivity in the assessment sheets, it is likely to remain a problem.

3 Earlier versions of the index included a complex scoring system which related separately to the inherent channel stability and to channel condition. Difficulties arose as to the weighting of scores and their interpretation. The simpler version based on the Australian ISC system was therefore adopted for the present. Once the database starts to develop it should be possible to derive a more appropriate scoring system if it is deemed necessary.

4 The willingness of a field worker to complete the data sheet is inversely related to its length. Researchers involved in other biomonitoring exercises were unwilling to spend the extra time on the geomorphology index. Non-geomorphologists found the classification of channel morphology and valley form taxing.

The final data sheets presented in this report are as a result of addressing the above problems. The separation of the baseline survey data from the monitoring data was thought to be particularly important. The baseline survey should be carried out by an experienced geomorphologist. It will provide the basis of a valuable data base on South African rivers. Data collection during the monitoring stage can be carried out by a trained technician. Training, together with better resources to aid identification of geomorphological features and interpretation of stream condition, are essential to the success of the programme.

The ISC (1997) gives a list of strategies to minimise error. A number of the points are relevant to establishing the most consistent quality of the geomorphological index.

*Measurement error*

How accurate are the measurements of indicators?

- training and evaluation was used in the ISC to minimise errors in indicators requiring field based measurements

*Inconsistencies between catchments*

Are the results from one catchment directly comparable with another?

- Photographic examples are provided in the users manual. This provides a standard for field data collection.

*Strategic bias*

Are results biassed?

- Bias is likely to occur if the data is collected with a particular agenda.

# 5. The monitoring programme

**Frequency of monitoring**

The geomorphological baseline assessment should be made when the sites are initially set up and after major hydrological events (10 year flood?) or following significant upstream disturbances such as a forest fire or a major land use change. Routine monitoring of channel condition should normally be made once a year during the low flow period to facilitate access to the channel.

**Levels of expertise and resources**

*The initial site rating and subsequent resurveys*

The baseline survey must be carried out by a professional geomorphologist with field experience. A field assistant could be usefully employed in assisting with measuring channel dimensions and undertaking bed material surveys. If a hydraulic survey is also to be carried out it would be advantageous to do this in co-operation with the geomorphologist. From past experience of IFR site assessments the base line survey would probably take one to two hours of dedicated time at the site, depending on the size of the channel and its complexity. Resources required include the data sheets and camera, a 50 or 100 m measuring tape and a standard template for particle size measurements.

*Monitoring*

Monitoring should be carried out by a trained technician or evaluator. Each site should take about half an hour to assess. The evaluator must be encouraged to move around the site and to get into the river whenever possible as it is not possible to assess the condition of the bed from the river bank. Resources required include the data sheets and a camera.

# 6. Conclusions and further development

The geomorphological index as presented in this report represents a first attempt to derive a simple method of assessing the geomorphological condition of a river channel. The index has been continuously modified through a relatively limited period of testing by a limited group of people. It needs to be more widely tested in a range of rivers by a number of evaluators. Feedback from these trials will inevitably result in some further modification. The scoring system will also need to be refined as the data base is developed.

Training of evaluators is seen to be an essential part of the programme and effective training methods still need to be developed. Improved training resources are also needed in the form of extended illustrated manuals, videos or CD ROMs.

Field research on the geomorphology of South African rivers is still in its infancy so that data on the physical characteristics of South African rivers are limited. The River Health Programme should go a long way towards building up a data base on the physical form and condition of our rivers. This data base will be invaluable in aiding the interpretation of observed river changes with respect to natural disturbance versus anthropogenic change. It must be remembered that rivers are dynamic systems which respond to the great hydrological variability characteristic of South Africa. In a natural system, channel erosion associated with extreme events is followed by a period of reconstruction, manifested by aggradation of channel bars, flood plain siltation and so on. It is recommended that as a preliminary to any regional biomonitoring programme a regional geomorphological audit should be carried out to assess the probable variation in channel form and process and to highlight any significant geomorphological events and their consequences over the more recent past.

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