THE RESPONSE OF THE TWO INTERRELATED RIVER COMPONENTS, GEOMORPHOLOGY AND RIPARIAN VEGETATION, TO INTERBASIN WATER TRANSFERS IN THE ORANGE-FISH-SUNDAYS RIVER INTERBASIN TRANSFER SCHEME

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Abstract

The Skoenmakers River (located in the semi-arid Karoo region of the Eastern Cape) is being used as a transfer route for water transferred by the Orange-Fish-Sundays River Interbasin Transfer Scheme. The change in the hydrological regime of this once ephemeral stream to a much bigger perennial river led to dramatic changes to both the physical structure and riparian vegetation structure of the river system. These changes differ for each of the three river sections, the upper, middle and lower reaches.

Qualitative, descriptive geomorphological data was gathered by means of field observations and this was then compared to the quantitative data collected by means of surveyed cross-sectional profiles at selected sites along the length of both the regulated Skoenmakers River and a non-regulated tributary of equivalent size, the Volkers River. Riparian vegetation data was gathered by means of plot sampling along belt transects at each site. A qualitative assessment of the vegetation conditions was also made at each site and then added to the quantitative data from the plot sampling. At each site the different morphological units were identified along the cross-section and changes in the vegetation and sediment composition were recorded. Aerial photographs were used as additional sources of data and observations made from these were compared to data gathered in the field.

The IBT had the greatest impact in the upper reaches of the regulated river. The pre-IBT channel in this river section was formed by low frequency flood flows but the hydrological regime has now been converted to base flows much higher than normal flood flows. Severe incision, erosion and degradation of both the channel bed and banks occurred. In the lower reaches, post-IBT base flows are lower than pre-IBT flood flows and, due to the increased catchment area, the impact of the IBT was better ‘absorbed’ by the river system. Aggradation and deposition increased for the regulated river in comparison to the non-regulated river due to more sediment introduced at the top of the system.

Complex interrelationships exist between the geomorphology and riparian vegetation of a river system and therefore it was evident that any change in the geometry of the river would lead to changes in the riparian vegetation and *vice versa*. The impact of the IBT on the riparian vegetation was therefore either direct (eg. loss of species due to inundation) or indirect (eg. loss of species due to loss of physical habitat). It was found that the biological diversity of the riparian vegetation (number of species and/or vegetation types) correlates with the physical diversity along the cross-sectional profile (number of morphological units present).

Water availability was found to be the basic underlying factor influencing the distribution and community composition of the riparian vegetation. A higher density of tree species was observed for the regulated river due to the availability of a constant supply of water to a former ephemeral system. A higher density and abundance of sedge species was also observed for the regulated river caused by a higher degree of deposition of finer sediment introduced at the top of the system.

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Chapter 1: Introduction

1.1 Introduction

River systems are usually confined within well defined spatial boundaries and represent open systems by which energy and material are exchanged with an external environment. The dynamic nature of such a fluvial system at any given point in time and space is a reflection of the integrated set of control mechanisms (Figure 1.1) upstream which determine the hydrological regime and the amount and type of sediment being transported.

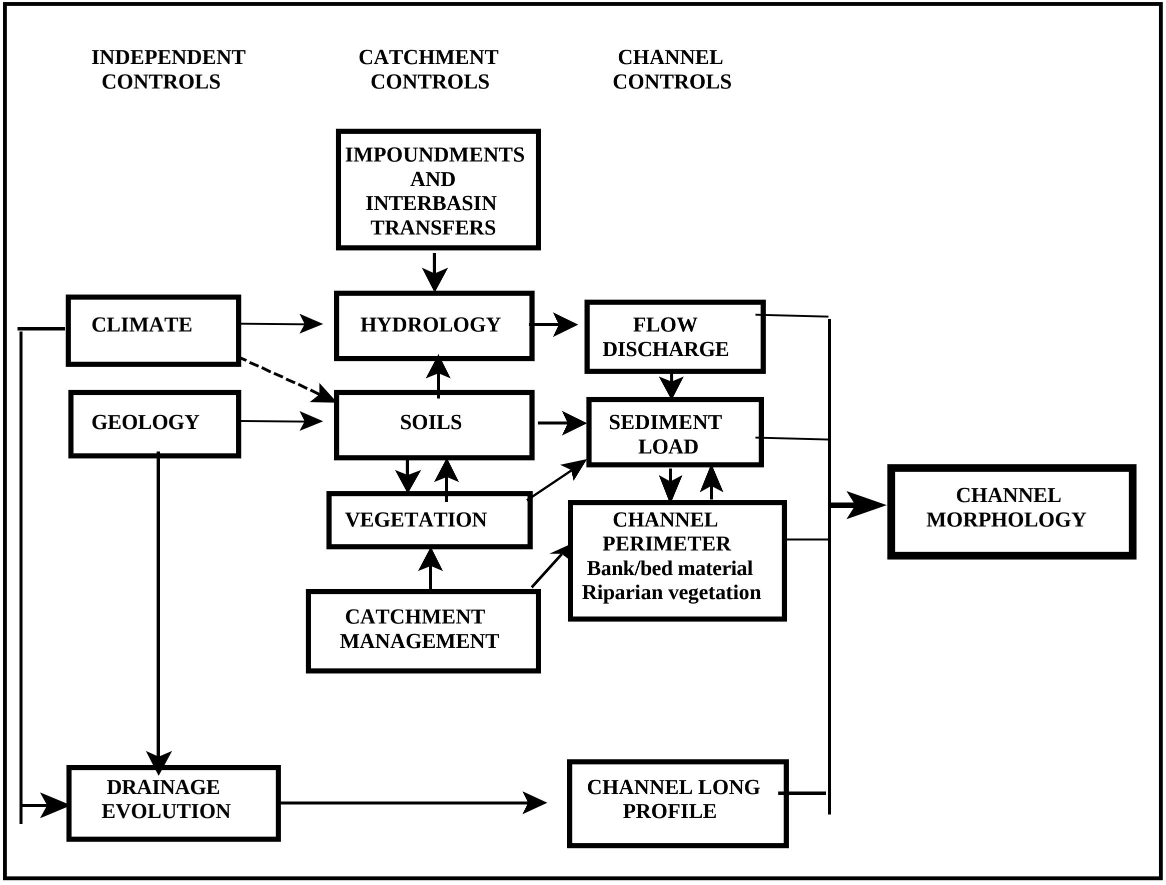

Figure 1.1: Control mechanisms of river morphology (Rowntree and Dollar, 1996:33).

The complex interactions between the variables of river morphology are evident from Figure 1.1 and therefore any change to any of these variables will clearly be reflected in the reaction of the river morphology. Interbasin transfers represent such a change. An Interbasin Transfer (IBT) can be seen as a mass transfer of water between geographically distinct river basins that has been developed to overcome water supply problems within a country (Petitjean and Davies,1988).

In South Africa IBTs have become essential to meet future water needs, especially due to the fact that the geographical distribution of water resources and that of the areas with a high rate of urban and agricultural development does not correspond. Such transfers of water will result in an increased flow discharge within the recipient channel and therefore it represents a direct and indirect impact on the river morphology.

Two sets of variables are recognised as significant in controlling river morphology. These are firstly, the catchment variables (regional scale) which determine the hydraulic and sediment regime of a river and secondly, the site variables (local scale) which determine and control channel stability, eg. bed and bank sediment characteristics and riparian vegetation (Rowntree,1991). As geomorphological research tended towards the local scale, the study of biological factors such as riparian vegetation has been facilitated.

Viles (1988) introduced the term *biogeomorphology* through which research attention can be focussed on the mutual relationship that exists between geomorphology and riparian vegetation; (i) the influence of geomorphology on the distribution of vegetation and (ii) the influence of vegetation on geomorphological processes and landforms. This mutual relationship has been adapted as the basis of assessing the influence an IBT will have on the form of the river as well the distribution and diversity of riparian vegetation. The outline of this assessment can be summarised as follows.

First of all, as in any research project, it was essential to clearly outline the specific *aim and objectives* for the research. This is put into context for this study by describing the *study area and* the Orange-Fish-Sundays River *Interbasin Transfer Scheme*, followed by a *literature review* that forms the basis of the research conducted. The *research design*, as an indication of how the objectives will be addressed, and the *methods*, which were applied to accomplish tasks outlined in research design, will be described. *Results* from fieldwork and other research will then be presented, followed by a *discussion* of these results and finally *conclusions* drawn from the research will be stipulated.

1.2 Aim and objectives

Complex interrelationships exist between riparian vegetation and the morphology of a river in a natural or non-regulated river system. In South Africa, where more and more river systems are becoming impacted by anthropogenic disturbances such as IBTs, the question now arises as to what would happen to these interrelationships within a regulated river system? The aim of this study is therefore to develop a better understanding of the response of river morphology and riparian vegetation to the influence of the IBT. In order to accomplish this, the research focussed on the following objectives:

- To emphasize the importance of ecological factors such as riparian vegetation within a fluvial geomorphological context;
- To indicate the specific interrelationships that exist between river morphology and riparian vegetation;
- To determine the processes within both geomorphology and riparian vegetation that will change as a result of the IBT; and
- To indicate the response of the morphology and riparian vegetation to the IBT.

1.3 Study area

1.3.1 Locality

In order to indicate the influence of an IBT on the geomorphology and riparian vegetation of a river, a comparison must be made between the natural and regulated states of the river. In most cases the inlet of the transferred water is through a secondary stream along the length of the main stream and therefore a direct comparison can be made between the areas above and below this inlet point to indicate the IBT influence. In the case of the Skoenmakers River (which was chosen as the study area) the inlet point of the IBT is right at the top of the catchment and therefore an alternative method was used to assess the influence of the IBT on the river system.

The method used for the assessment of the influence of the IBT involved a comparison of a similar river within the same catchment as the regulated Skoenmakers River. The Volkers River (natural) has been chosen for such a comparison as this river lies within the same catchment (area of ± 590km^2) and has similar rainfall statistics and a subcatchment area almost the same as that of the Skoenmakers River. These two rivers form part of the Sundays River catchment (approximately

21 250km^2) which drains a large area of the semi-arid Karoo region of the Eastern Cape (Figure 1.2). Due to the similarity of these two rivers and the fact that they are located within the same catchment, this forms an ideal situation for assessment of an IBT's influence on semi-arid river systems and their vegetation.

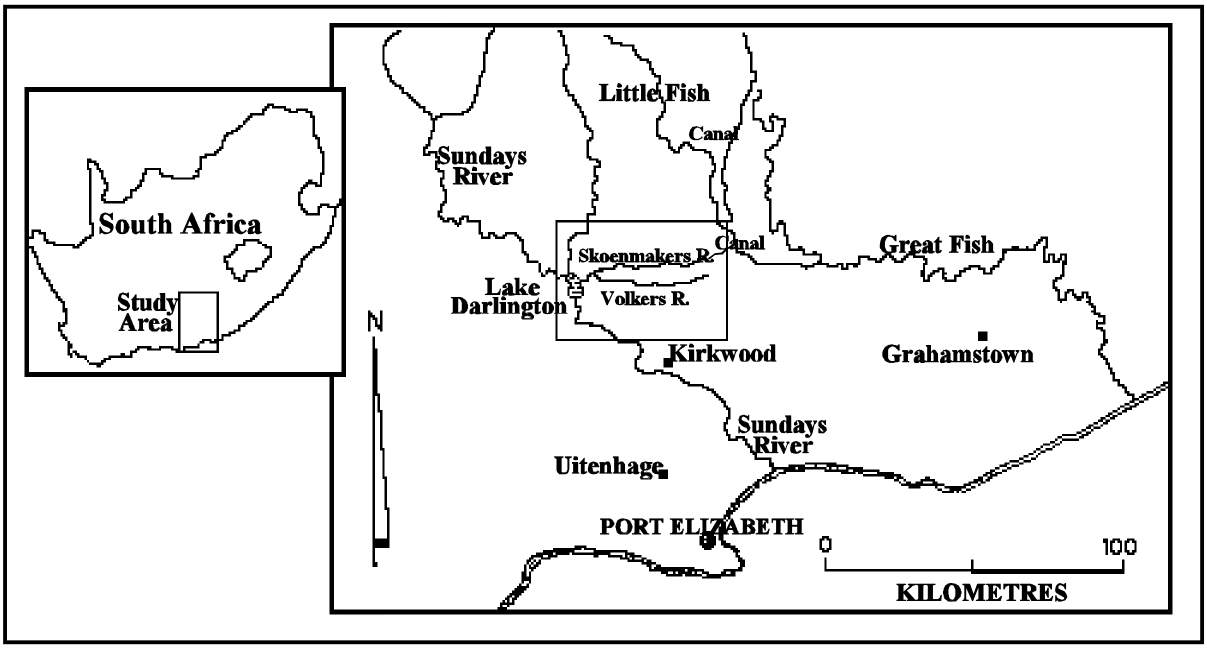

Figure 1.2: Location of the study area within the context of the Orange-Fish-Sundays River Interbasin Transfer Scheme.

The regulated Skoenmakers River has a subcatchment area of approximately 270km^2 (See Figure 1.3) and a main channel length of approximately 48km. It forms part of the Orange-Fish-Sundays River IBT which involves water transfers from both the Orange River and its tributary, the Caledon River, to the Great Fish and Sundays Rivers. Under natural conditions the Skoenmakers River was a small ephemeral stream (similar to the Volkers River) but the transfer of water from the Orange River since the late 1970s and early 1980s has converted it into a much bigger, perennial river.

The Volkers River (subcatchment area of approximately 290km^2 and main channel length of approximately 50km) is a typical ephemeral, gravelbed river, as found in semi-arid regions of the Eastern Cape, and has its source within the Zuurberg mountain range near Kirkwood.

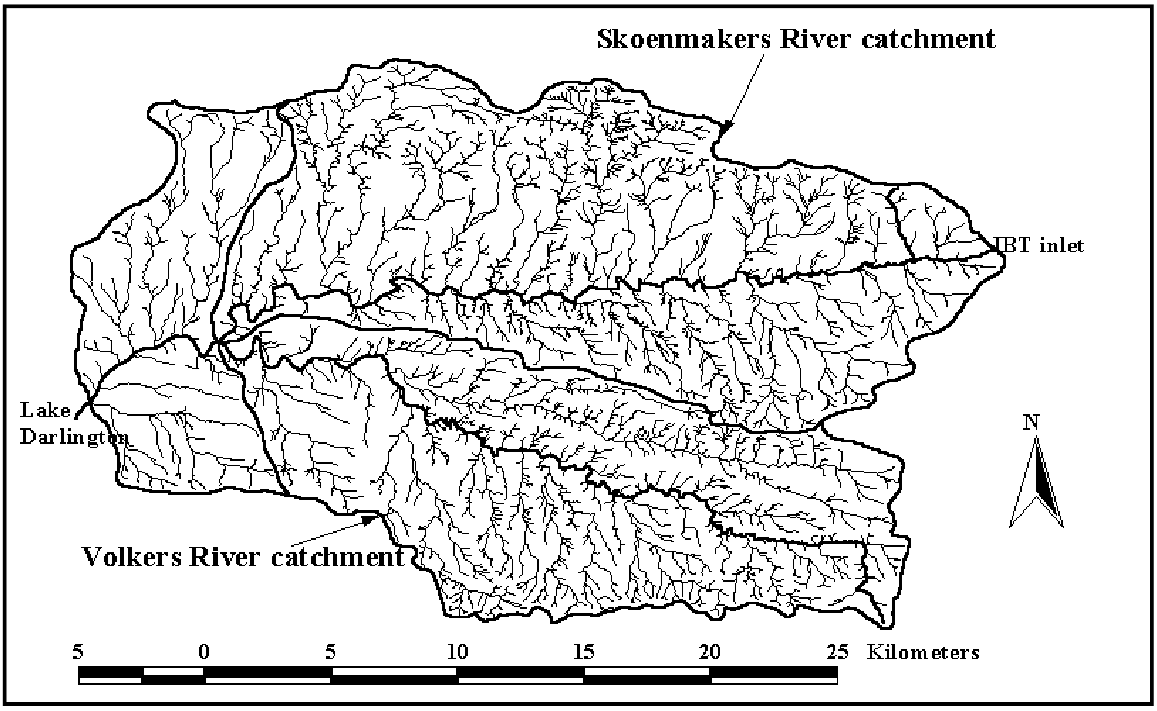

Figure 1.3: Subcatchments for the Skoenmakers and Volkers River.

1.3.2 Geomorphology

The long profiles for both rivers have been constructed by means of digitized Arc/Info covers. These are illustrated in Figures 1.4 and 1.5 below. Reach breaks, based on a significant change in the channel gradient, are indicated by broken lines.

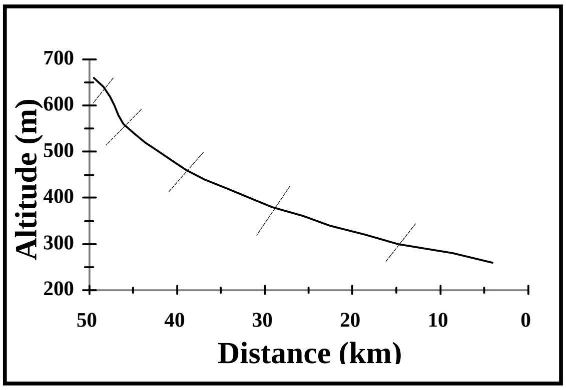

Figure 1.4: Long profile of the Volkers River.

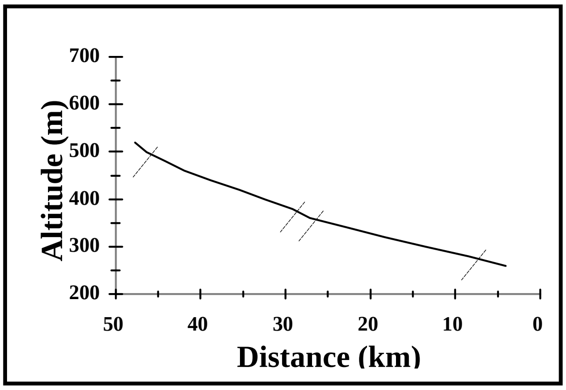

Figure 1.5: Long profile of the Skoenmakers River.

These two semi-arid rivers (like most of the Eastern Cape rivers) deviate from simple models derived from northern temperate rivers. Long profiles do not follow the conventional concave form and tend to have a more convex profile due to rejuvenation in the recent geological past (Rowntree and Dollar, 1996).

The Skoenmakers River tends towards an almost rectilinear profile, with a significant knickpoint in the middle reaches of the river which is probably the result of a junction at this point for the main stream with one of the bigger tributaries for the Skoenmakers River catchment.

The 'normal' gradation from bedrock to alluvial channels is disrupted, due to the overall steepness of the long profile of many Eastern Cape rivers, combined with local step-like features. As expected, bedrock dominates the steepest headwater areas and alluvial sections become more frequent downstream. These areas, however, are interspersed with rock outcrops so that even the lower reaches may have significant bedrock and cobble sections. It is often the case that the channel bed may be bedrock and the banks are composed of alluvium (Rowntree and Dollar, 1996).

In semi-controlled channels, where the river is migrating laterally, one bank may be bedrock whilst the other is alluvium. Observations in the field confirmed this statement for the upper reaches of the Skoenmakers and Volkers Rivers. For modern Eastern Cape rivers the upper reaches, above the major axis of rejuvenation, are the most likely location for meanders to develop (Rowntree and Dollar, 1996). Both the Skoenmakers and Volkers Rivers have a strong meandering channel form.

1.3.3 Geology

The geological composition of the two catchments is illustrated in Figure 1.6. The dominant Groups are represented by the Beaufort and Ecca Groups of the Karoo Sequence. These two Groups are characterised by highly erodible shale stone (Ecca), and mudstone and sandstone (Koonap) which contributes to sediment input into the channels. Rapids are formed in areas where bedrock intrusions (mostly dolerite) occur. The Beaufort Group consists of only the Koonap Formation whilst the Ecca Group includes formations like Fort Brown, Ripon, Dwyka, Salnova, Waterford, etc. (See Figure 1.6).

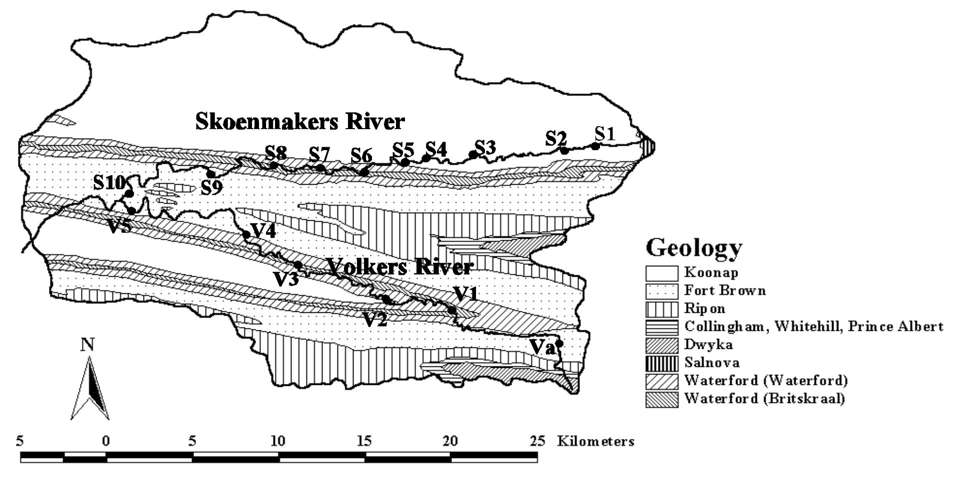

Figure 1.6: Geology of the catchment (Data source: 1:250 000 geological map).

1.3.4 Catchment vegetation

The vegetation of the catchment is dominated by the vegetation types found within the Nama Karoo Biome. The dominant vegetation type is the Eastern Mixed Nama Karoo vegetation type which consists of a complex mixture of shrub- and grass-dominated vegetation types subjected to dynamic changes in species composition and is highly dependent on seasonal rainfall events. Trees, mostly *Acaia karroo*, are mainly found along the dry river beds (Hoffman, 1996).

1.3.5 Climate

The study area falls in the semi-arid Karoo region of the Eastern Cape and therefore within the summer rainfall area of South Africa. The highest average monthly rainfall occurs during December (Figure 1.7).

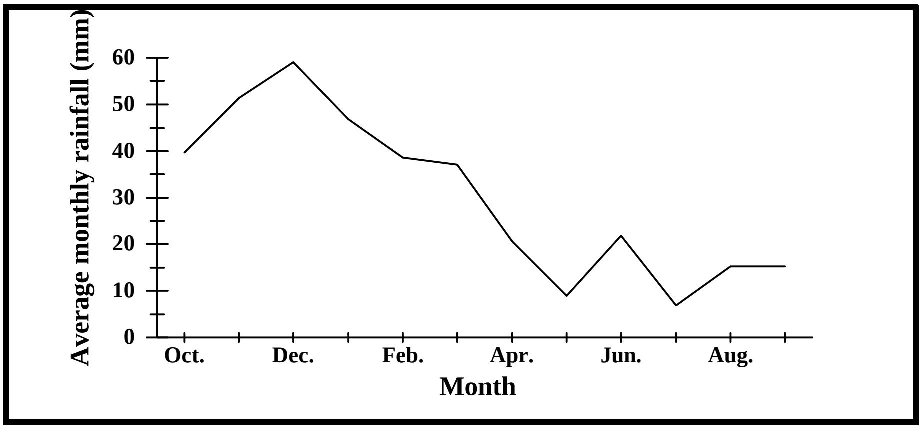

Figure.1.7: Average monthly rainfall measured at De Mistkraal Dam for the period 1990 to 1997 (Data source: Department of Environmental Affairs and Tourism).

1.3.6 The Orange-Fish-Sundays River Interbasin Transfer Scheme

As early as 1928 diversion of Orange River water to the Fish River had been proposed by the Director of the Department of Irrigation. In 1962 a comprehensive plan for the development of the Orange River was announced (Van Robbroeck, 1979).

The Orange-Fish tunnel was completed in 1975, with its intake standing freely in the basin of the Gariep Dam. Flow is controlled from underground outlet works located 7km from the end of the tunnel (Van Robbroeck, 1979).

Some of the water let down the Fish River is diverted from the Elandsdrift weir near Cookhouse to the Cookhouse tunnel and then diverted into the Little Fish River (See Figure 1.8). Most of this water had been diverted by a diversion weir and pumped over the watershed to the Skoenmakers River at the Wellington Grove pumpstation (Van Robbroeck, 1979) but as a result of the high costs involved (R33 000 p.m.) an alternative method of diversion had to be found.

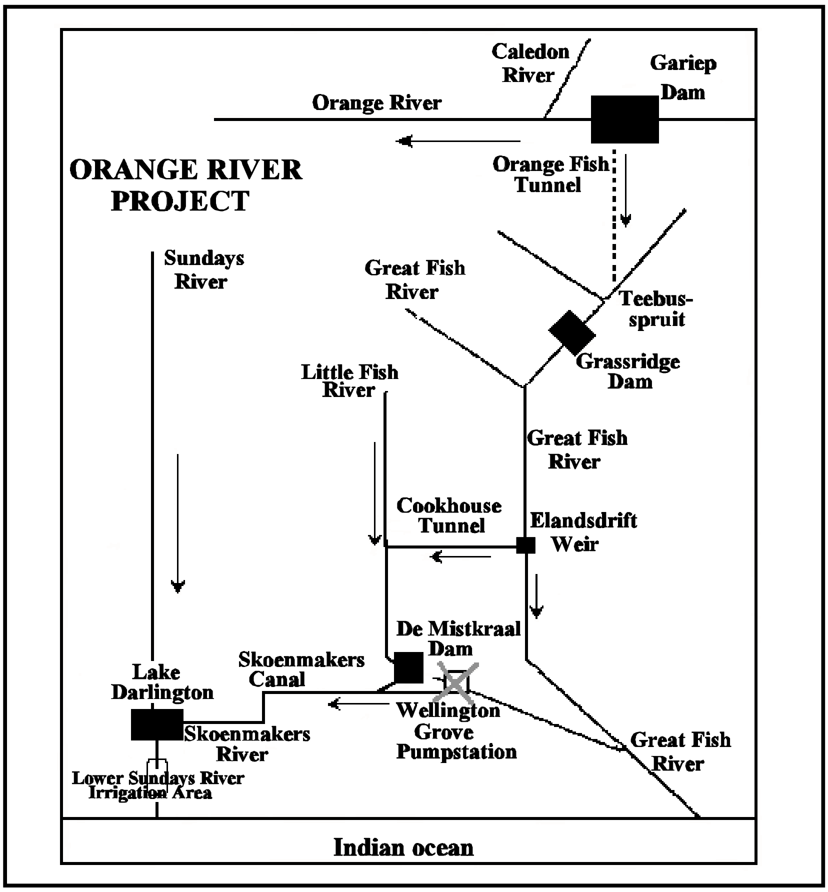

Figure 1.8: Schematic outline of the Orange-Fish-Sundays Interbasin Transfer Scheme (Petitjean and Davies 1988).

In 1985 De Mistkraal Dam was completed and water was let down the Skoenmakers Canal into the Skoenmakers River. From here the water flows into Lake Darlington and let out into the Sundays River as a supply to irrigation farmers and Port Elizabeth area. The amount of water let down depends on the demand downstream and especially from the irrigation farmers in the Lower Sundays River irrigation area.

Water release from the dam is interrupted during May and June when repair work is done to the Skoenmakers Canal. During this ‘dry period’ the Skoenmakers River continues to flow for approximately two weeks after which streamflow almost comes to a standstill in the river and large pools are formed. During floods upstream of De Mistkraal Dam water releases into the Skoenmakers Canal is cut off and the water is allowed to flow over the dam wall into the Little Fish. These flood events, therefore, do not have any effect on the Skoenmakers River (Faber, *pers. comm.*).

Before the completion of De Mistkraal Dam, water released down the canal was restricted to only about four cubic metres per second by the Wellington Grove Pumpstation. After the completion of the dam the full capacity (up to 22 m^3s^{-1}) of the Skoenmakers Canal can be utilised. It is evident that the IBT has resulted in dramatic flow changes in the Skoenmakers River. The river has been changed from an ephemeral stream, typically found in semi-arid Karoo region of the Eastern Cape, to a perennial river.

Chapter 2: Literature Review

2.1 Introduction

This chapter presents a review of literature related to the geomorphological and vegetation processes operating in a fluvial system and the variables which control these processes. The interrelationship between riparian vegetation and river morphology was used as a guideline for the specific literature reviewed and will be outlined in this chapter. This review also focusses on the variables and processes likely to change due to the influence of the interbasin water transfer.

2.2 River morphology

2.2.1 Geometry / Channel form

River morphology is an important component of fluvial geomorphology and determines the quantity and quality of instream habitats available for living organisms (Gilvear *et al.*, 1995). Any disturbance (natural or anthropogenic) would also be clearly reflected in the channel morphology and the channel would adjust to compensate for the disturbance (Rowntree and Wadeson, 1999).

According to Rowntree and Dollar (1996) channel form is controlled by four interrelated groups of variables:

i. The long profile which determines distribution of gravitational energy along a channel;
ii. River flow that provides kinetic energy for erosion and transportation of sediment;
iii. Sediment which contributes to channel composition through deposition; and
iv. Additional resistance to erosion eg. riparian vegetation.

An important variable of channel form is the cross-sectional profile, as a lot of information can be obtained from the adjustments of the two cross-section components of depth and width to outside influences. According to Knighton (1987) width is one of the most adjustable components of channel geometry. The width of streams also determines much of the biology of stream habitats (Gordon *et al.*, 1992). Width and depth adjust rapidly to altered conditions. The scale and rate of these adjustments depend on environmental factors (Gordon *et al.*, 1992). The quantity of water moving through the cross-section affects the channel morphology due to changes in the processes of erosion and deposition (Rowntree and Wadeson, 1999). These two processes play an important role in local bank conditions.

2.2.2 Bank condition

It is important to remember that all fluvial systems are dynamic and have the ability to change form in response to forces active upon them. In the short term the fluvial system can attain stability or equilibrium marked by balance between erosion and deposition.

Bank erosion is the result of moving grains on the bank region subjected to transverse gravity pull due to the lateral inclination of the bank (Ikeda and Izumi, 1990). The degree of erosion (or deposition) depends on the balance between the erosive force of flow and erodibility of the sediment and these are both affected by riparian vegetation. Erosion occurs when grains or assemblages of grains are removed from the bank face by flow. This erosion process depends on the geotechnical properties of bank material, for example the presence or absence of cohesion.

According to Rowntree and Wadeson (1999), the classification of banks is done on the basis of their material composition, shape and the degree and types of erosion. Banks are generally divided into cohesive and non-cohesive based on their boundary composition. Cohesive banks have developed in bedrock and/or sediment with a high silt-clay content.

Cohesive banks are usually eroded by the detachment and entrainment of aggregates or crumbs of soil that are much less susceptible to flow erosion than non-cohesive banks. In non-cohesive banks, material is usually detached and entrained grain by grain. The third type of bank is called stratified banks. These are alluvial banks which usually consist of layers of non-cohesive and cohesive materials. Generally, non-cohesive layers erode more quickly than cohesive ones and this lead to generation of shelves where cohesive material underlies non-cohesive material (Thorne, 1990). These shelves are very important in terms of vegetation and morphology and will be discussed in more detail at a later stage.

Bank accretion is the opposite of erosion and it occurs when the bank is stable and sediment input to the basal area is greater than sediment output downstream (Thorne, 1990). Point bars represent such deposits and play (like shelves) a very important role in stabilising the river channel and in the establishment of marginal vegetation.

2.2.3 Channel types

According to Rowntree and Dollar (1996) there are two broad channel types, i.e. bedrock and alluvial controlled channels. Bedrock channels are so-called ‘controlled channels’ as their form is determined by bedrock controls rather than river flow. Alluvial channels on the other hand are formed within the sediment that is being transported by the river, eg. gravel, sand and silt.

Alluvial rivers form channels through the interaction of flowing water and a mobile boundary. In practice most alluvial bank deposits exhibit cohesion. This could be ascribed to the presence of silt and clay fractions or the binding effect of vegetation (Illgner, 1991). These factors contribute to the fact that alluvial rivers are not static and continually change their position as a consequence of hydraulic forces acting on their beds and banks (Hails, 1977). According to Hickin and Nanson (1984), curved river channels shift laterally by erosion of the concave (outer) bank and deposition of point bars at the convex (inner) banks.

In meandering river channels like the Skoenmakers and Volkers Rivers, morphological units such as point bar depositions are very important aspects when it comes to stabilising the channel. A classification of bar types and morphological units of an alluvial river is given in Figure 2.1 and Table 2.1 (Rowntree and Wadeson, 1999).

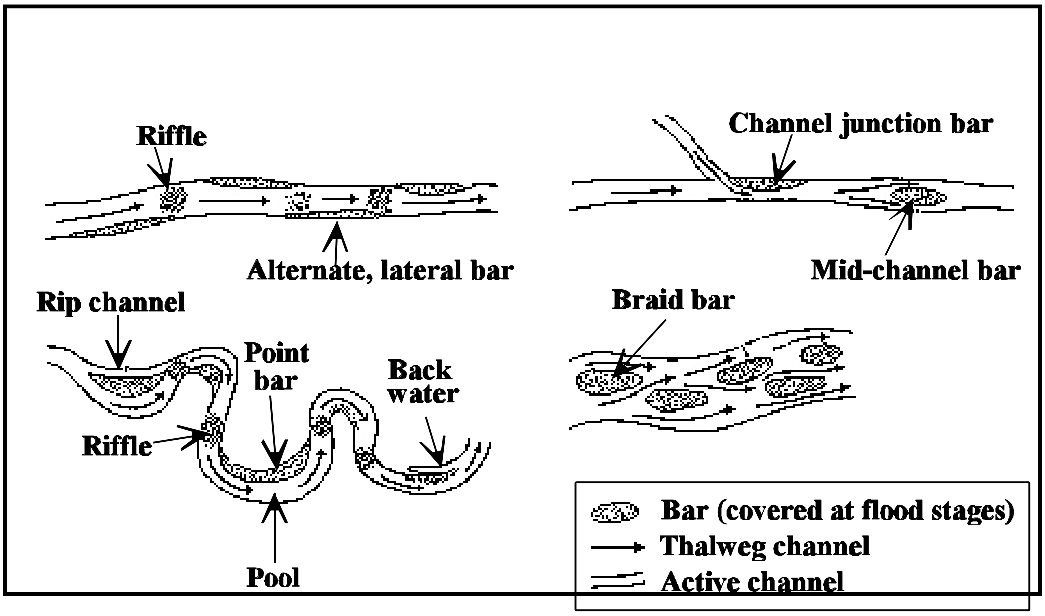

Figure 2.1: Classification of the bar types and morphological units of alluvial river channels (Rowntree and Wadeson, 1999:44).

Table 2.1: Classification of the morphological units (After Rowntree and Wadeson, 1999:45).

Morphological unit	Description
pool	A topographical low point in an alluvial channel caused by scour; characterised by relatively finer bed material.
backwater	Morphologically detached side channel which is connected at the lower end to the main flow.
rip channel	High flow distributary channel on the inside of point bars or lateral bars; may form a backwater at low flows.
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.
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 flood plain.
transverse or diagonal bar	The bar forms across the entire channel at an angle to the main flow direction.
riffle	A transverse bar formed of gravel or cobble, commonly separating pools upstream and downstream.
rapid	Steep transverse bar formed from boulders.
step	Step-like features formed by large clasts (cobble and boulder) organised into discrete channel spanning accumulations; steep gradient.
channel junction bar	Forms immediately downstream of a tributary junction due to the input of coarse material into a lower gradient channel.
lee bar	Accumulation of sediment in the lee of a flow obstruction.
mid-channel bar	Single bars formed within the middle of the channel, with strong flow on either side.
braid bar	Multiple mid-channel bars forming a complex system of diverging and converging thalweg channels.
bench or shelf	Narrow terrace-like features formed at the edge of active channel abutting on to the macro-channel bank.
islands	Mid-channel bars which have become stabilised due to vegetation growth and which are submerged at high flows due to flooding.

2.2.4 Cross-section

A cross-section can be defined as a number of morphological units, and each related to a specific set of hydro-geomorphic processes (as described in Table 2.1) and distinctive riparian vegetation communities (Rowntree, 1991). According to Rowntree and Wadeson (1999) a cross-section should account for the full set of fluvial features across the valley floor. Figure 2.2 is presentation of such a cross-section.

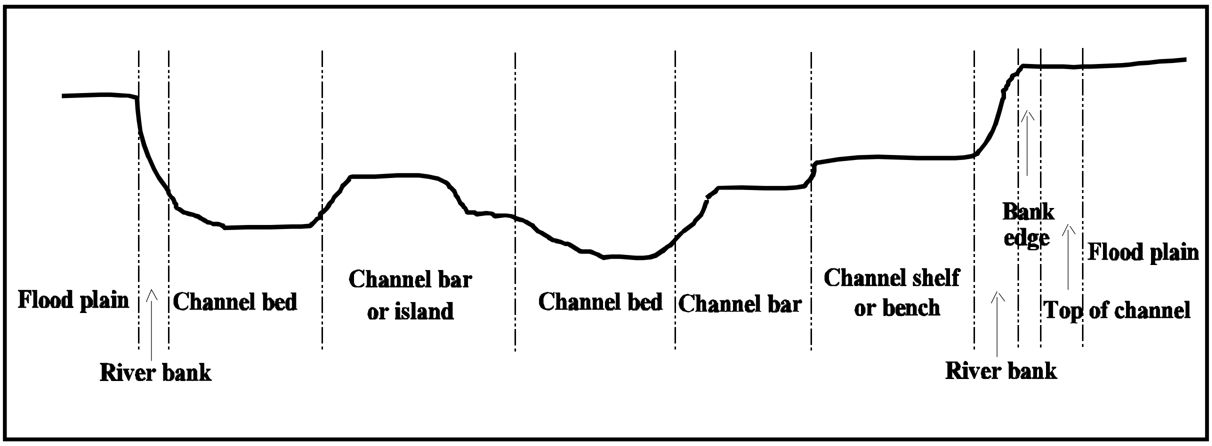

Figure 2.2: Cross-section of a channel indicating the different morphological units (After Rowntree, 1991:29).

2.2.5 Long profile

It is necessary to emphasize the importance of the change in channel gradient downstream as a factor influencing the relationships between riparian vegetation distribution and river morphology (Hupp, 1990). The long profile indicates such a downstream change in gradient and is therefore one of the most important components of morphological research on any river channel.

The general course of a long profile is as follows; steep gradient for the upper reaches, decreasing downstream until a very gentle gradient is achieved in lower reaches. This profile usually results in a concave curve with a division of rivers into upper, middle and lower reaches (Mangelsdorf *et al.*, 1990). The most commonly used spatial scale within a river system is the reach. The length of reaches depends on its position within the stream network as well as the heterogeneity of local control variables (Rowntree and Wadeson, 1999).

According to Schumm (1977) the upper, middle and lower reaches can be linked to the degree of erosion and deposition. Although these two morphogenic forces can be active along the whole river course, he subdivided river courses into three zones, depending on the dominant force active (Mangelsdorf *et al.*, 1990):

- Zone 1: Production => Upper reaches;
- Zone 2: Transfer => Middle reaches; and
- Zone 3: Deposition => Area of the mouth.

It is evident from this classification system that certain assumptions in terms of sediment yield can be made. According to Rowntree and Dollar (1996), a number of changes in sediment dynamics can be observed when moving down a river. Sorting processes carry the finer particles downstream and therefore the upper reaches will be characterised by coarse material like boulders and gravel. Lower reaches, on the other hand, will carry more sand and silt.

2.2.6 Basis of fluvial geomorphology

Hickin (1984:111) made the statement that “the physical science of fluvial geomorphology is flawed by the fact that it does not cope well with processes less easy quantifiable and physically or statistically manipulable”. The theory and empirical basis of fluvial geomorphology have seen radical developments this century. There has been a pronounced shift from general qualitative description of river-related landforms to detailed quantitative analysis of fluvial processes. All these changes had a direct influence on our understanding of river systems and it is now possible to incorporate another river component, riparian vegetation, into the holistic approach to river and/or catchment management.

2.3 Riparian Vegetation

2.3.1 Functions of riparian vegetation

The specialised plant communities in riparian zones perform a variety of general functions. Rogers and Van der Zel (1989) divided these functions into the following four basic groups:

- (a) Flow-based functions
  1. Control water velocity;
  2. Controls of erosion of riverbeds and banks; and
  3. Water retention
- (b) Physico-chemical functions
  4. Increased deposition rates;
  5. Nutrient retention; and
  6. Sink for pollutants
- (c) Biological functions
  7. Enhancement of biotic diversity;
  8. Enhancement of heterogeneity (patchiness) of the habitat; and
  9. Resistance to the invasion by alien species
- (d) Human use functions
  10. Food and resources; and
  11. Recreation sites.

"The role of riparian vegetation is considerably understated in fluvial geomorphology and certain kinds of vegetation-related fluvial processes are virtually overlooked, or poorly understand at best" (Hickin, 1984:112). A review of literature on riparian vegetation confirmed this statement. From this review it was evident that the available literature concentrates on two basic functions: (i) the indirect relationships between vegetation-water or sediment yield-river morphology and (ii) the direct impact of boundary vegetation on the channel morphology.

Riparian vegetation acts as a buffer of the floodplain against floods and against dry seasons by storing shallow ground water (Illgner, 1991). Vegetation disrupts the flow of water in two distinct ways (Gray and McDonald, 1989); firstly, bank vegetation induces local deposition on banks by reduction of the near-bank velocities, therefore decreasing shear stress on banks and promoting sediment deposition on the channel shelf (Rowntree, 1991). Secondly, vegetation in the form of single, isolated trees enhances scour around the trunk and therefore accelerates local bank erosion. It modifies the width, height and stability of a geomorphic surface and often indicates breaks in a slope, therefore separating the alluvial features.

One negative factor often attributed to riparian vegetation is the utilisation of water which would otherwise either flow down the river (Rogers and Van der Zel, 1989) or be stored in the groundwater supplies. According to Illgner (1991) vegetated banks are drier than unvegetated ones for the following reasons:

(i) vegetation prevents 15-30% of precipitation from reaching the soil surface; and
(ii) increased evapotranspiration loss from the soil reduces soil moisture.

Vegetation increases the organic matter content of soil and therefore improves its structure. This results in higher water storage capacity of the topsoil (De Jong, 1994). It also provides habitat for other organisms together with geomorphology and therefore it is evident that changes in vegetation lead to changes in the habitat (Tsujimoto *et al.*, 1996).

It was evident from the reviewed literature that a lot of research has focussed on the influence of vegetation on channel roughness (Cowan, 1956; Petryk and Bosmajian, 1975; Powell, 1978; Engman, 1986; Gregory and Gurnell; 1988; Thorne, 1990 and Illgner, 1991). According to Rowntree (1991) the roughness contribution of vegetation depends on interaction between water depth and flow velocity and height, flexibility and density of the vegetation. Dense vegetation (increased roughness) can reduce channel capacity during floods, leading to more frequent over bank flows.

For the purpose of this study, attention was given to the role vegetation plays in forming the channel and the influence of the geomorphology on the vegetation. This review therefore, focussed more on this specific function of riparian vegetation and will now be discussed in more detail.

2.3.2 Influences on geometry

Controversy concerning the role of vegetation in geomorphological processes arises because the role of vegetation is often subtle and complex. Vegetation type, density, age, health, etc. are important factors with direct control on the vegetation's influence which may either enhance or reduce bank stability (Thorne, 1990). Bank drainage can be an indirect effect of riparian vegetation on bank stability. Vegetated banks are drier and better drained than unvegetated banks, which enhance the bank stability.

Channel form and the lateral stability of a river may be influenced significantly by the binding properties of vegetation growing on and near the river banks. Since vegetation binds sediment and increases its strength, well-vegetated banks will be associated with lower ratios of width-to-depth than poorly vegetated banks (Hickin, 1984). Riparian vegetation increases channel depth by approximately 63% and decreases width approximately 55% on average in gravel rivers in Colorado (Ikeda and Izumi, 1990).

Vegetation also modifies the interface region between flowing water and the stream bank and therefore leads to modification of the hydraulic and mechanical properties and ultimately affects the resistance of the bank to erosion (Gray and McDonald, 1989). According to Viles (1990), the size, shape, growth characteristics and density of vegetation are important factors influencing erosion. Vegetation communities are not static and therefore changes in vegetation often lead to spectacular changes in erosion rates and distribution and thus, ultimately, to the geometry of the channel. Cycles of build-up and erosion may occur as vegetation communities grow and are then killed off by an excess of sediment, leading to the development of distinctive landforms.

Geomorphologists have long argued about the role of riparian vegetation on channel morphology. An ongoing question exists on the effect of trees compared to grass, and the distinction between grassy and woody vegetation in terms of their effects on bank stability. It was evident from the literature reviewed that researchers agree a good grass cover tends to protect banks against erosion and encourages deposition of sediment. Trees on the other hand leads to the development of deeper, narrower channels (Keller and Swanson, 1979; Murgatroyd and Ternan, 1983; Gregory and Gurnell, 1988; Viles, 1990; Van Coller, 1992; Rowntree and Dollar, 1996; Trimble, 1997).

It is recognised that differences in channel form under different types of vegetation are caused mainly by the relative disturbance of vegetation above ground rather than by differences in shear strength resulting from different root systems (Gregory and Gurnell, 1988). Trimble (1997) found that grass reaches have an average width-to-depth ratio which is only 67% to 72% that of tree-lined banks. According to Van Coller (1992) an increase in woody vegetation cover may have major stabilizing effects on channel bars and islands and can therefore be seen as an important component influencing future morphology. Riparian vegetation help stabilises the channel by forming channel bars and islands due to flow resistance and sediment trapping.

It was evident from this review that the role of riparian vegetation within the fluvial system is of major importance. To understand this role, it is essential to understand the sensitive nature of the riparian ecosystems and the processes operating within the riparian system.

2.3.3 Riparian ecosystems

The riparian zone can be seen as the aquatic-terrestrial ecotone and therefore the focal point for the interactions among diverse disciplines (hydrology, geomorphology, botany, zoology, etc.) combined in modern fluvial ecology. At the macro-scale the extent and the composition of the riparian ecosystems are powerful organizers of the structural and functional characteristics of streams, as riparian vegetation can often override or modify the basic geomorphological and hydraulic constraints (Cummins 1992). It is evident therefore that riparian ecosystems are both a product and formative agent of watershed geomorphology.

According to Rowntree (1991:28) "riparian zones[1] are the most impacted ecosystems in southern Africa because of their exposure to natural and human related disturbances". These ecosystems are most sensitive to human influences and potentially most threatened ecosystems (Haslam, 1978; Rowntree, 1991; Naiman *et al.*, 1992 and Nilsson *et al.*, 1997). Riparian ecosystems in arid and semi-arid regions are under continuing pressure from water development activities, eg. IBTs (Stormberg, 1993).

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[1] Riparian zones are the zones adjacent to and directly influenced by a river channel (Rowntree, 1991:28).

Nilsson and Jansson (1995:55) made the statement that "riparian ecosystems are central elements in many landscapes". This is true as riparian ecosystems act as hotspots of species richness and are therefore key elements in the regulation and maintenance of landscape biodiversity. Riparian ecosystems support more species diversity, higher population densities and greater plant and animal biomass than any other habitat (Kondolf *et al.*, 1987).

Riparian ecosystems are organised into specific drainage patterns and are effectively interspersed into the landscape despite a small total area. They act as filters between adjacent elements, therefore also as buffers against environmental change. Riparian ecosystems can also be seen as the most important natural corridors for flows of energy, matter and species through the landscape (Nilsson and Jansson, 1995). Nilsson *et al.* (1991) stated that riparian ecosystems can be used as indicator systems in assessing the effects of water regulation on the river margin. A study of the response of riparian vegetation to an IBT is therefore essential to add to the understanding of the diverse river system as a whole.

2.3.4 Morphological diversity

The numbers of both communities and species of riparian vegetation largely depend upon a diversity of the habitat (Hellawell, 1988). According to Hughes (1990), species diversity is the highest in the midreaches of a river because of the fact that these reaches exhibit the highest environmental heterogeneity. On the other hand, the upper and lower reaches have lower diversity values associated with a more homogeneous environment. Hughes recognised, however, that species composition is a function of the disturbance regime and other environmental variables and the role of disturbance therefore decreases the predictability of species composition from site attributes.

Nilsson *et al.* (1989:77) found that "the predicted covariation in species diversity and environmental heterogeneity is consistent with the intermediate disturbance hypothesis which proposes that species diversity is maximised by the spatio-temporal heterogeneity resulting from moderate disturbance." They found that the only factors correlating with total species richness were substrate heterogeneity and substrate fineness. Total species richness increased with substrate heterogeneity and was at maximum at intermediate levels of disturbance.

Morphological diversity plays a major role in the spatial distribution of riparian vegetation along the length of the river as well as on a cross-sectional profile. There are other factors, however, influencing the vegetational structure of river systems that are also worth looking into.

2.3.5 Spatial distribution

It was evident from Section 2.3.4 that the downstream zonation of vegetation can be explained by the changes in the morphological diversity. It is important to realise that this diversity is greatly affected by the specific characteristics of the sediment present (Haslam, 1978; Gordon *et al.*, 1992; Rogers and Van der Zel, 1989). The sediment can be seen as one of the most important physical variables controlling plant distribution downstream. According to Haslam (1978) the other controlling factors include:

(i) Water flow (quantity);
(ii) Channel width;
(iii) Channel depth;
(iv) Distance downstream; and
(v) Gradient.

Rates and types of sediment deposition have been shown to be important factors affecting riparian vegetation distribution patterns. Most bottomland sediment available for seedling establishment is alluvial, thus hydraulic sorting of sediment sizes and the rate of bed, bar or bank accretion are important geomorphic processes influencing vegetation distribution. Many riparian species are therefore restricted to a narrow range of sediment types that allow successful seed germination (Hupp, 1988).

Patterns of riparian species distribution are strongly associated with the geomorphic stage of adjustment (Simon and Hupp, 1990). Deep-rooted plants can withstand erosive forces and therefore it is more likely to find these species in the upper reaches where erosion represents the dominant morphogenic force. In comparison, plants usually associated with deposition are represented by shallow-rooted species with a varying rooting level (that is, roots that will grow with the accumulating sediment). It is therefore evident that the upper reaches will be associated with woody vegetation, whilst grass and reed species tend to be dominant in depositional areas along the river, like the lower reaches and channel bars (Van Coller, 1992).

Van Coller (1992) pointed out that the physical landforms do not control species distribution directly but rather the fluvial and hydrological processes associated with the landforms. Three gradients were identified to explain species distribution along streams:

(i) Longitudinal gradient:

Physical variables and hydro geomorphic processes change in a downstream direction and can be explained by the longitudinal gradient.

(ii) and (iii)Vertical and horizontal gradients:

A small change in elevation above (vertical gradient) or horizontal distance away from (lateral gradient) the active channel results in definite changes in flooding frequency, water table fluctuations, fluvial landform, as well as soil and sediment type.

According to Van Coller and Rogers (1996) the vertical, lateral and longitudinal gradients, combined with patchy geomorphological settings, lead to an extremely diverse and dynamic environment that influences species distribution patterns. Vegetation units or types[2] are also closely related to differences in degree of bedrock control and type of morphological unit. These relationships between the riparian vegetation and the physical environment result in specific site preferences for specific vegetation types.

2.3.6 Site preferences

Plant communities are defined as a collection of plants showing a definite association with each other (Kent and Coker, 1992). This association implies that certain species are found to grow more frequently in certain locations and environments than would be expected by chance. The reason for this preference of a specific site depends on the specific requirements in terms of environmental factors, eg. water, drainage, soil nutrients, etc. (See Figure 2.3). Species will be absent from locations or sites where optimum thresholds in terms of the environmental factors are exceeded. These sites are called the *zone of intolerance* (Figure 2.3).

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[2] Vegetation type can be defined as a collection of common species which possesses a similar vegetation structure (vertical profile) and share the same set of ecological processes (Low and Rebelo, 1996:2).

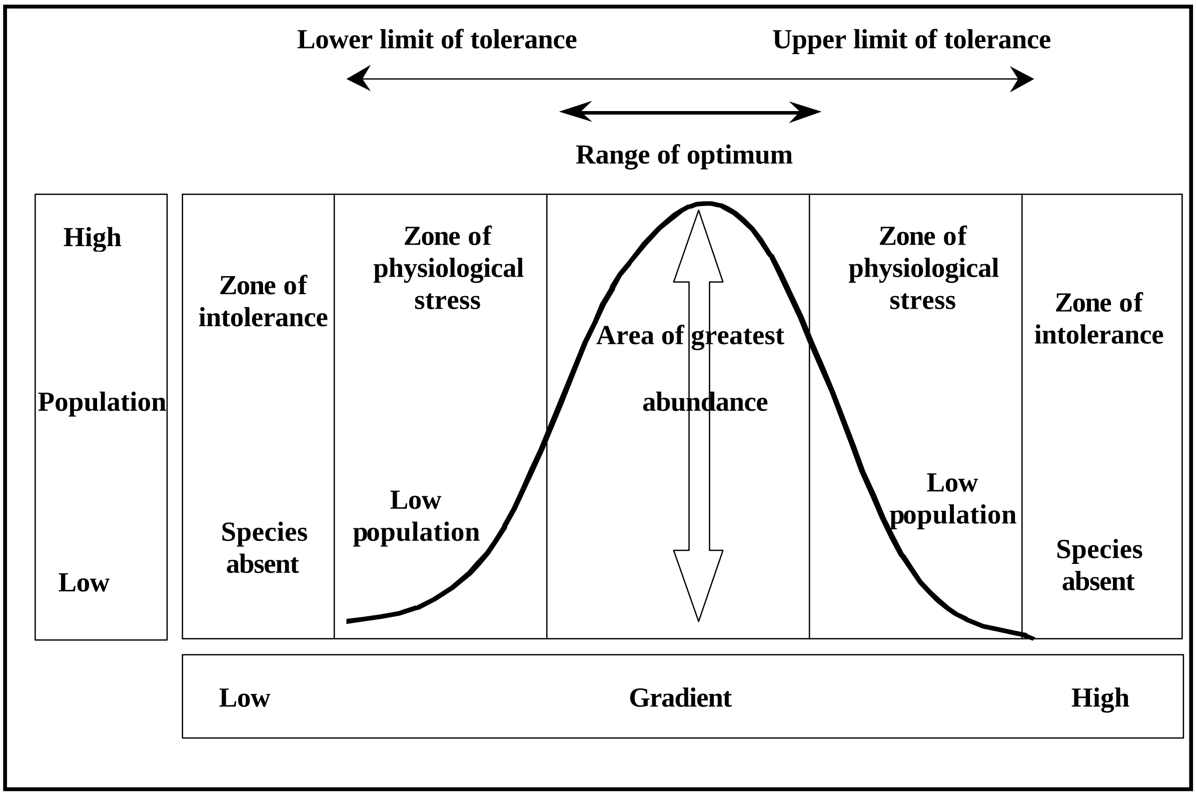

Figure 2.3: The Gaussian or normal curve of plant species response to a single environmental factor (Kent and Coker, 1992:14).

Erosion and sedimentation result in a variety of fluvial landforms with different surface substrata and there is a close correlation between type of fluvial landform and vegetation distribution patterns (Van Coller, 1992). The statement above is supported by research by a number of other authors indicating that the distinct site preferences of bank vegetation can be linked to the morphological change of the channel (and vice versa), as well as the sediment dynamics within the channel (Gregory and Gurnell, 1988; Thomas, 1988; Viles, 1988; Hupp, 1990; Simon and Hupp, 1990; Thorne, 1990; Trimble, 1990; Rowntree, 1991 and Collett, 1996).

Different sets of hydrogeomorphic processes form the floodplain and the channel shelf, with different suites of vegetation characteristic of each (Hupp, 1988). Small reed infested bars tends to trap sediment, thereby increasing the height above the water and therefore also their chance of survival. A more favourable sediment, and therefore a habitat, is being provided for the new community of plants through this process (Illgner, 1991).

In ephemeral channels of semi-arid areas, woody species often colonise channel bed and bars. Channel shelves serve as habitat for herbaceous vegetation and riparian shrubs (Rowntree, 1991). It is therefore evident that the availability of these habitats plays an important role in the establishment of vegetation and its structure along river channels.

2.3.7 Site availability

The process of plant succession along rivers is usually initiated on new alluvium deposited during flood-stages. New space for the deposited sediment has to come from the destruction of older sections of the bank or floodplain. This constant replacement of older soil-vegetation complexes by new successional units results in a specific structure of riparian vegetation (Gill, 1973).

The removal of existing vegetation and/or sediment, as well as deposition of sediment and vegetation on existing sites, is determined by the disturbance of flooding. Examples of vegetation sites created in such a way include exposed patches of bedrock and the cracks in between rocks and alluvial sediment depositions. These are important regeneration sites with the variety in texture and organic matter content as the most important variables.

2.3.8 Exotic riparian vegetation species

A review of South African literature on vegetation-morphological relationships shows the potential impacts of alien vegetation on river morphology as one of the major concerns (Rowntree 1991; Collett 1996). Alien species have the tendency to invade disturbed areas along rivers because of the fact that it is easier for these species to establish in the new conditions. IBTs represent such a disturbance in the riparian zone and therefore it enhances alien invasions (Collett 1996).

Riparian zones are more prone to an invasion compared to terrestrial environments, mainly because they are exposed to periodical natural and human related disturbances. Naturally unstable geomorphic units such as river bends are more susceptible to an invasion. Perennial availability of moisture also plays a major role in establishment of exotics (Rowntree, 1991). It is therefore evident that water availability will play a major role in the processes operating in the riparian vegetation structure and therefore the geomorphology.

Riparian species have higher transpiration rates than terrestrial species and therefore require a permanent supply of water for at least part of the year (Van Coller and Rogers, 1996). Water availability can be seen as the primary factor limiting riparian vegetation abundance in semi-arid regions. Arid streams are water-limited on an annual or seasonal basis because of high discharge fluctuations. Small changes in discharge and riparian water availability lead to measurable changes in riparian vegetation abundance (Stormberg, 1993).

Some riparian zones, especially in semi-arid areas, experience short seasonal floods and long dry seasons when water availability is low, at least for shallow-rooted plants. The most important factors influencing the riparian water balance in any river section are the magnitude and timing of surface inundation and bank storage. The latter will depend largely on the sectional morphology and the depth and porosity of the soil (Rogers and Van der Zel, 1989).

2.4 Hydrology

2.4.1 Downstream hydraulic geometry

The distance downstream and stream gradient has a significant influence on the factors that determine the downstream hydraulic geometry (width, depth and velocity). Changes in width, depth and velocity are related to variation in channel geometry and flood intensity. Increased stream gradient usually increases stream power with a concomitant increase in channel width, a decrease in channel depth and an increase in channel roughness (Hupp, 1988). The form ratio of width-to-depth (w/d) is an important parameter influencing reaction of the channel to change in discharge.

The relationship between the channel dimensions and the discharge has been described by Leopold and Maddock (1953), cited in Rowntree and Wadeson, (1999) through the concept of hydraulic geometry. This concept assumes that discharge (Q) is the dominant independent variable and that the dependent variables are related to it as power functions:

$$W = aQ^b$$

$$d = cQ^f \qquad W = \text{width},\ d = \text{depth},\ V = \text{mean velocity}$$

$$V = kQ^m$$

From the continuity equation,

$$Q = w.d.v = aQ^b.cQ^f.kQ^m$$

it follows that

$$a.c.k = 1 \text{ and } b+f+m = 1$$

The expression b+f+m should therefore always equal unity so that a change in width (b) will be compensated for by a change in depth (f) and velocity (m).

It is evident from this empirical formula that downstream hydraulic geometry reflects the way in which channel form changes as discharge increases in the downstream direction. It must be related to a specific discharge frequency, usually the 1.5 year recurrence interval or mean annual flood which should be approximately equivalent to the bank full or channel forming discharge (Rowntree and Wadeson, 1999).

2.4.2 Discharge fluctuations

Fluctuations of discharge are characterized by repetitions of flood and base flow or a low flow stage. During the flood stage deformation of the river bed occurs and during the base flow stage riparian vegetation growth period and deposition of fine sediments are initiated (Tsujimoto and Kitamura, 1996).

Flood stages or peak flows are needed for the rearrangement of the substratum (through scour) and to reconnect floodplain habitats with the channel, therefore to restore the habitat heterogeneity. Sustained base flow fluctuations are also needed to restore biodiversity and production within the shallow water habitats. It is important, however, that in a regulated river daily changes in flow should not exceed the range of variation that occurred before regulation (Stanford, *et al.*,1996).

The regime of semi-arid streams is characteristically unsteady and therefore relationships between process and form are less obvious and clear-cut than in humid areas. This is partly due to the fact that high-magnitude events have such a dominant influence on the geomorphological and hydrological components of the river system (Knighton and Nanson, 1997).

Dominant discharges in semi-arid areas do not relate to the annual flood but to some lower frequency flood (Rowntree and Dollar, 1996). The channels of these areas take longer to recover from extreme events and the effects of floods are therefore preserved for a long time, especially where vegetation is sparse (Knighton and Nanson, 1997). This is mainly due to a lack of flows of intermediate magnitude which construct the channel (Rowntree and Dollar, 1996). The question now arises as to how rivers in semi-arid regions will react to major changes in discharge, brought about by IBTs. Knighton and Nanson (1997) stated that "...the channel form may never become completely adjusted to coexisting process" due to the long recovery times within semi-arid and arid river systems.

2.4.3 IBTs[3] and their influence

South Africa's river systems are highly impacted by anthropogenic influences such as IBTs, landuse changes and impoundments. The problem confronting geomorphologists and water managers today is the assessment of the importance of natural and anthropological factors. Human impact must be recognised and effects minimised, but it must also be realised that rivers are dynamic systems and therefore change is an inherent characteristic of fluvial landforms and vegetation.

IBTs will lead to alterations of catchments as an entire river or a section of a river becomes the *donor* of water, while the other becomes the *recipient*. Interbasin transfer schemes involve several types of transfer routes, eg. *pipes*, *canals*, and *natural water courses* (Snaddon and Davies, 1997), transferring water from impoundments or reservoirs located upstream within the same or another catchment.

The question arises as to how the effects of IBTs differ from the effects of dams on rivers. In most cases, impoundments result in a reduction of water flow for the recipient stream (Church, 1995 and Fergus, 1997) whilst water transfers lead to an increased flow within the recipient stream (Gibbins, *et al.*, 1996). River regulation by IBTs is often far more complex than regulation caused

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[3] "An Interbasin Transfer (IBT) is the mass transfer of water from one geographically distinct river basin to another and has been developed in order to overcome supply problems throughout the country" (Petitjean and Davies, 1988:819).

by storage of water (Snaddon and Davies, 1997). It was evident from the review of available literature that far more attention is given to the effect of impoundments on the catchments involved.

Interbasin transfers are frequently technically well assessed but the ecological aspects are almost totally ignored. The only system in southern Africa with some pre-IBT data is the Great Fish River, mainly through the foresight of early researchers who undertook surveys of the river system before the IBT was completed (Davies *et al.*, 1993).

All the other schemes operating in southern Africa at the beginning of the 1990s were planned without any form of comprehensive environmental or ecological impact assessment (Petitjean and Davies, 1988). Attention was given to the visual (aesthetic) and terrestrial environmental impacts rather than to those effects which appeared in aquatic and terrestrial ecosystems months or years after completion. River regulation schemes have therefore been approved without considering the effect on the river's ecological integrity and biodiversity and if these factors will be maintained in the long term (Nilsson *et al.*, 1997).

River regulation can be seen as environmental manipulation due to the fact that the natural environment of organisms becomes modified. Where ecological conditions are destroyed or modified beyond tolerance levels these organisms (plants and animals) die and/or communities are changed and replaced by others (Hellawell, 1988). Most studies on the ecological effects of IBTs concern invertebrates and fish (Nilsson *et al.*, 1991). Environmental impact assessments of IBTs in the past lack knowledge of the impact on riparian vegetation. Today, however, emphasis is on *multi-disciplinary assessment* and therefore the incorporation of river components such as riparian vegetation is facilitated.

2.5 Conclusions

In comparison to literature on other components of the fluvial system, riparian vegetation is by far the least documented of all. Also, in literature on the subject of the ecological effects of river regulation, most attention is given to the reaction of the fauna of the river to this disturbance. The vegetation component of the river is often not even considered in the assessment of IBT influences on the environment.

Literature on river regulation showed one major flaw in that no clear distinction is made between the influence of *IBTs* and that of *impoundments* on the recipient streams. Although impoundments form part of the transfer scheme, the effect of the IBT on the natural transfer routes (river channels) should be considered on its own, as their influences on geomorphological and vegetation processes differ significantly. A summary of the aspects from the literature review found to be of relevance on this study and therefore the impact of an IBT will now be presented.

2.5.1 River morphology

(a) Geometry or channel form

River morphology is an important component of fluvial geomorphology and determines the quantity and quality of instream habitats available for living organisms (Gilvear *et al.*, 1995). The cross-sectional profile is an important variable of channel form, as a lot of information can be obtained from the adjustments of the two cross-section components of depth and width as a response to outside influences (Knighton, 1987). Width and depth adjust rapidly to altered conditions and the rate of these adjustments depend on environmental factors (Gordon *et al.*, 1992). It is important, however, to remember that all fluvial systems are dynamic and have the ability to change form in response to forces active upon them. In the short term the fluvial system attains stability or equilibrium marked by balance between erosion and deposition which can be seen in the local condition of the banks.

(b) Long profile

The long profile gives an indication of the downstream change in gradient. This profile is one of the most important components of morphological research on any river channel as it plays an important role in the explanation of downstream changes in the river morphology and riparian vegetation (Hupp, 1990). The general course of a long profile is as follows; a steep gradient in the upper reaches, decreasing downstream until a very gentle gradient is achieved in lower reaches. Changes in the channel gradient contribute to the sediment sorting processes and therefore in the riparian vegetation distribution patterns and processes. The degree of erosion and deposition can be linked to the distance downstream (Schumm, 1977). Each section of the river along the long profile can be linked to the dominant morphogenic force active, i.e. production (erosion) in the upper reaches, transfer in the middle reaches and deposition in the lower reaches.

2.5.2 Riparian Vegetation

(a) Influences on geometry

Controversy concerning the role of vegetation in geomorphological processes arises because the role of vegetation is often subtle and complex. Vegetation type, density, age, health, etc. are important factors with direct control on the vegetation's influence which may either enhance or reduce bank stability (Thorne, 1990).

Geomorphologists have long argued about the role of riparian vegetation on channel morphology and an ongoing question exists on the effect of trees compared to grass. According to Rowntree (1991) the most important distinction between grassy and woody vegetation can be made in terms of their effects on bank stability. It was evident from the literature reviewed that researchers agree that a good grass cover tends to protect banks against erosion and encourages deposition of sediment. Trees, on the other hand, lead to the development of deeper, narrower channels.

(b) Morphological diversity

It was evident from the literature review that the numbers of riparian vegetation communities and species largely depend upon a diversity of the habitat (Hellawell, 1988). Nilsson *et al.* (1989:77) found that the only factors correlating with total species richness were sediment heterogeneity and sediment fineness. Total species richness increased with sediment heterogeneity which, in turn, influences the morphological diversity as finer sediment tends to be deposited at the bottom of the banks or as bar depositions. Coarser material is deposited further away from the water's edge as well as higher up the catchment along the upper reaches of the longitudinal profile. This change in morphological diversity along the longitudinal gradient is reflected in the spatial distribution of the riparian vegetation.

(c) Spatial distribution

Rates and types of sediment deposition have been shown to be important factors affecting riparian vegetation distribution patterns (Haslam, 1978; Gordon *et al.*, 1992; Rogers and Van der Zel, 1989). Most bottomland sediments available for seedling establishment are alluvial, thus hydraulic sorting of sediment sizes and the rate of bed, bar or bank accretion are important geomorphic processes influencing vegetation. Many riparian species are therefore restricted to a narrow range of sediment types for successful seed germination (Hupp, 1988).

Van Coller (1992) pointed out that the physical landforms do not control species distribution but rather the fluvial and hydrological processes associated with the landforms. Three gradients were identified to explain species distribution along streams:
(i) The longitudinal gradient which explains the changes to the physical variables and hydro geomorphic processes in a downstream direction, (ii) the vertical gradient and (iii) the horizontal gradient. A small change in elevation above (vertical gradient) or distance away from (horizontal gradient) the active channel results in definite changes in flooding frequency, water table fluctuations, fluvial landform, as well as soil and sediment type.

Erosion and sedimentation result in a variety of fluvial landforms with different surface sediment types which, in turn, lead to distinct site preferences of riparian vegetation. A number of authors observed that these site preferences of bank vegetation can be linked to the morphological change of and the sediment dynamics within the channel (Gregory and Gurnell, 1988; Viles, 1988; Simon and Hupp, 1990; Thorne, 1990; Trimble, 1990; Rowntree, 1991 and Collett, 1996).

(e) Water availability

Water availability can be seen as the primary factor limiting riparian vegetation abundance in semi-arid regions. This is mainly due to the fact that riparian species have higher transpiration rates than terrestrial species and therefore require a permanent supply of water for at least part of the year (Van Coller and Rogers, 1996). Stormberg (1993) found that small changes in the discharge and riparian water availability lead to measurable changes in riparian vegetation abundance. This is of direct relevance to this study as the Orange-Fish-Sundays IBT led to major changes in the discharge and flow regime of the Skoenmakers River.

2.5.3 Hydrology

(a) Discharge fluctuations

Fluctuations of discharge are characterized by repetitions of flood and base flow or a low flow stage. The low flow stage is important in terms of riparian vegetation's growth period as the deposition of fine sediment is initiated (Tsujimoto and Kitamura, 1996). Flows of intermediate magnitude are geomorphological important as these flows help construct the channel (Rowntree and Dollar, 1996).

The flow regime of semi-arid streams show a lack in flows of this magnitude and therefore high-magnitude events such as floods have a dominant influence on the geomorphological and hydrological components of the river system (Knighton and Nanson, 1997). Dominant discharges in semi-arid areas do not relate to the annual flood but to some lower frequency flood (Rowntree and Dollar, 1996). The channels of these areas take longer to recover from extreme events and the effects of floods are therefore preserved for a long time, especially where vegetation is sparse (Knighton and Nanson, 1997).

(b) IBTs and their influence

South Africa's river systems are highly impacted by anthropogenic influences such as IBTs, landuse changes and impoundments (Davies *et al.*, 1993). IBTs will lead to alterations of catchments as an entire river or a section of a river becomes the *donor* of water, while the other becomes the *recipient*. River regulation can be seen as environmental manipulation due to the fact that the natural environment of organisms gets modified. Sometimes these modifications go beyond tolerance levels of the aquatic and riparian organisms (plants and animals) which leads to a change and replacement of the existing communities and species by others (Hellawell, 1988). Most studies on the ecological effects of IBTs concern invertebrates and fish (Nilsson *et al.*, 1991), whilst environmental impact assessments of IBTs in the past lack knowledge of the impact on riparian vegetation. Today, however, emphasis is on *multi-disciplinary assessment* and therefore the incorporation of river components such as riparian vegetation is facilitated.

Chapter 3: Methods

3.1 Introduction

Chapter 3 consists of three parts: firstly, a presentation of the research design as a guideline of the approach to the research problem. This will be followed by a discussion of the methods used for data collection and sampling of the vegetation and physical environment of the rivers. To complete the chapter, the procedure of data analysis will be presented.

3.2 Research design

A research design can be defined as "...the planning of any scientific research from the first to the last step. It is a programme to guide the researcher in collecting, analysing and interpreting observed facts." (Bless and Higson-Smith, 1995:63). The research design used in this study (Figure 3.1) is based on the "*pre-test/post-test*" design described by Bless and Higson-Smith (1995).

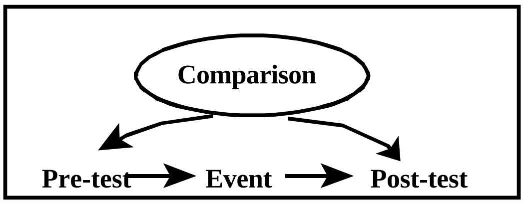

Figure 3.1: Schematic outline of the research design (Bless and Higson-Smith, 1995:69).

Dependant variables before (*pre-test*) and after (*post-test*) the event that is expected to bring about changes is measured and, as a result, the scores on this measurement can be compared over time. The morphology and riparian vegetation of the Skoenmakers River were used as the dependant variables for this project and the response to the Orange-Fish-Sundays River IBT (the *event*) was assessed over a period of approximately 20 years, since the completion of the IBT in the late 1970s. Pre-IBT aerial photographs and other pre-IBT data as well as the present conditions of the Volkers River were used as reference conditions.

Due to a lack of detail in pre-IBT data, a comparison of natural and regulated rivers were used to indicate any changes brought about by the IBT. Nilsson *et al.* (1991) also made use of this method for their research and called this type of study a *comparative study*. The comparison of the river in its natural state with the river that has been disturbed by the IBT should give an indication of the degree of disturbance in the regulated river system. This kind of pre-test/post-test approach, however, is not without difficulties.

River systems are dynamic, constantly changing over time, and therefore it is possible that other changes occurred at the same time as the IBT. It is therefore evident that these changes (and not the IBT) could have been responsible for the change in the dependant variables of geomorphology and vegetation. This is particularly true for river morphology and riparian vegetation when a long period of time has elapsed between the pre- and post-tests. The 20-year period in which the IBT has been active in the Skoenmakers River could therefore be of major importance in this study and should be kept in mind throughout the research process of data collection, analysis and interpretation.

3.3 Data collection

Aerial photographs (1960 to 1990) and maps of the research area were studied and the two river catchments were digitized (from the 1:50 000 topographical maps), using the PC Arc/Info GIS software package. This was done in order to indicate reach breaks (distinct changes in the gradient) and to assist with site selection along the length of the rivers.

Data derived from the GIS covers was compared to observations in the field and study sites were chosen to be representative for both the botanical and geomorphological diversity of each reach. Figure 3.2 indicates the distribution of the sites chosen along the two rivers.

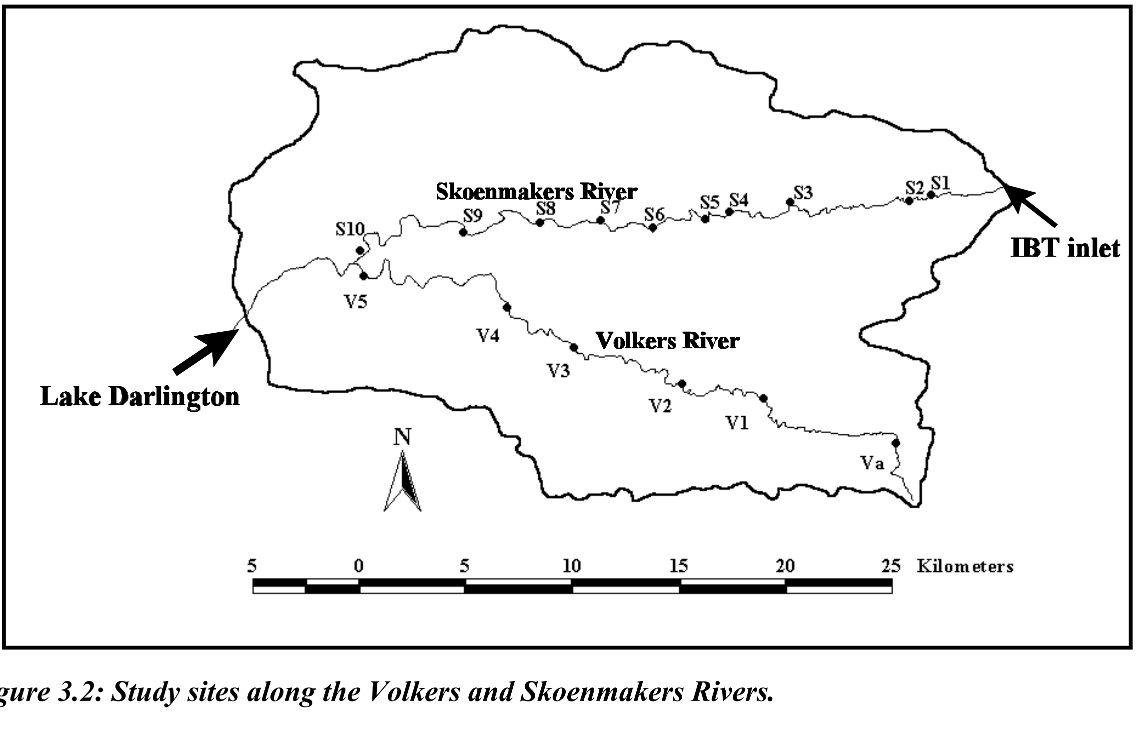

Figure 3.2: Study sites along the Volkers and Skoenmakers Rivers.

The number of sites chosen along each river depended upon the botanical and geomorphological variety between the individual sites of the same reach as well as accessibility. Six representative sites were chosen along the Volkers River. In comparison, ten sites were chosen for the Skoenmakers River to account for possible higher diversity of the riparian vegetation. Sites were also selected according to the distance downstream (measured from GIS covers). This attribute is essential for comparison of two sites along two different rivers as similar site characteristics (eg. width, depth, etc.) are expected at the same distance downstream for the individual rivers. Table 3.1 presents the summary of the different sites according to the distance downstream and location along the length of the rivers. Division of the two rivers into the three sections, upper, middle and lower reaches, was based on the reach breaks identified in Figures 1.4 and 1.5.

Table 3.1: Selected sites along the Volkers and Skoenmakers Rivers.

VOLKERS RIVER			**SKOENMAKERS RIVER**		
Site	**Distance downstream (km)**	**Section of the river (Reach)**	**Site**	**Distance downstream (km)**	**Section of the river (Reach)**
Va	3.51	Upper	S1	3.79	Upper
V1	12.20	Upper	S2	4.27	Upper
V2	17.83	Upper	S3	11.52	Upper
V3	24.91	Middle	S4	15.21	Middle
V4	29.67	Middle	S5	16.88	Middle
V5	40.13	Lower	S6	20.21	Middle
			S7	23.42	Lower
			S8	26.74	Lower
			S9	31.59	Lower
			S10	39.75	Lower

3.3.1 Hydrology

Post-IBT runoff data (monthly and daily flows) for the Skoenmakers River was obtained from the Department of Water Affairs and Forestry (DWAF) in Cradock. This data is only representative of the period 1978 to 1988 as the gauging station recording this data was closed down in 1989.

The only other flow data available for the Skoenmakers River after 1989 were the releases from De Mistkraal Dam as there are no other gauging stations along the river. Due to the fact that no data was available before 1978 for the Skoenmakers River and that there are no gauging stations along the Volkers River, no pre-IBT flow data was available.

3.3.2 Physical environment

The physical characteristics of each site were described by means of a basic survey of the cross-sectional profile which included a measurement of the width and depth of the macro-channel. Also, a description was made of the sediment present for each morphological unit. A number of easily measurable variables which can be related to vegetation patterns have been chosen as basis for data collection:

(i) Channel form:
- distance downstream;
- channel width; and
- channel depth

(ii) Vegetation controls:
- elevation above the channel bed;
- distance away from the active channel;
- type of morphological unit;
- type of surface sediment; and
- geology.

A total station was used for an accurate survey of the river channel (width and depth). These surveys were carried out during periods of low flow conditions in the Skoenmakers River. Significant points (eg. breaks in bank and bed slope, sediment change, etc.) were recorded along the cross-section. Morphological units, such as the top of the channel, bank’s edge, etc., was identified using the definitions after Rowntree (1991) (See Figure 2.2). Channel depth was estimated directly from the total station data by calculating the average depth of the total recorded points along the cross-section.

In addition to this data, surveyors' maps (1:6 000) of the Skoenmakers River in the pre-IBT stage (1970) were obtained from the DWAF in Cradock and the data derived from these maps were compared to the cross-sectional profiles derived from the fieldwork.

Identification of the different morphological units along the cross-section was based on the definitions outlined in Table 2.1. Two sediment samples (between 300 g and 500 g) were taken for each morphological unit present, eg. the banks, shelves, channel bars, etc. Two additional samples were also taken where a significant change in the sediment and vegetation type at each morphological was observed. Using an auger, all the samples were taken within the first 30cm of the soil surface.

Assessment of the bed and bank conditions of the channel was done by means of on-site evaluation of the sediment type which was then recorded on field forms (See Tables 4.3 and 4.4). Any change in the geology at each site was recorded as well.

3.3.3 Riparian vegetation

A number of factors influenced the choice of the method used for vegetation description:

(i) The purpose of the study;
(ii) The scale of the study;
(iii) The overall habitat type; and
(iv) The resources available

Research into the relationship of vegetation and geomorphology is essentially descriptive and therefore vegetation data was collected and described in both a quantitative and qualitative manner. In plant-geographical work, purely statistical approaches can be misleading or unproductive (Zimmerman and Thom, 1982). The parameters used as basis for vegetation data collection and used in the qualitative description of distribution patterns include the following (Appendix 4):

(i) Type (grass, reed, shrub or tree);

(ii) Diversity (mono-stand, mixed or climax vegetation);
(iii) Species (indigenous or exotic) (See Appendix 6);
(iv) Density (sparse, moderate or dense);
(v) Height (short, medium or tall);
(vi) Extent (wide, medium or narrow);
(vii) Health (healthy, fair or poor);
(viii) Age (immature, mature or old);
(ix) Position (bottom, middle or top of bank, or bar); and
(x) Spacing (continuous, close or wide).

Quantitative data on the vegetation was collected at each site by means of belt transects[4]. The main purpose for using transects in this study was, "...to describe maximum variation over the shortest distance in the minimum of time" (Kent and Coker, 1992:54). Each transect was set up perpendicular to the channel and divided (according to the Braun-Blanquet method) into selected, representative, homogeneous transects or plots of a specific minimum size (Werger, 1973).

Plot size varies from one vegetation type to another and therefore methods of progressive doubling of plot size and resulting species-area curves (Figure 3.3) were used to establish the size (Kent and Coker, 1992). Species-area curves for the Skoenmakers and Volkers River indicated 50m^2 to 200m^2 plots for woody species and 25m^2 (5x5m) for grasses and sedges. These plot sizes were also influenced by the width of the riparian zone at the specific site.

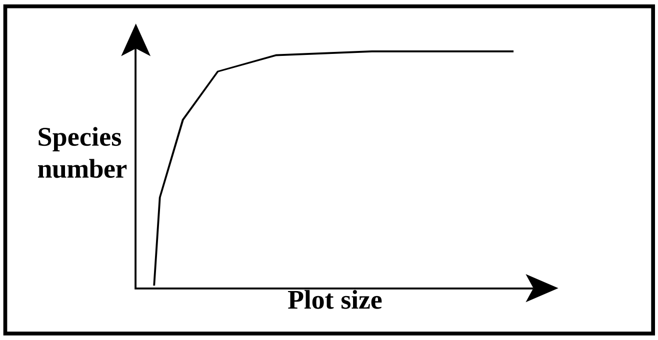

Figure 3.3: The Species-area curve (Kent and Coker, 1992:41).

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[4] Belt transects are formed where quadrats are laid out next to each other or along the transect line (Kent and Coker, 1992).

The basal and foliage areas (square metres) were measured for each species and the number of individuals for each species was counted within each plot. This data was then recorded onto data sheets (Appendix 5) and fed into a spreadsheet programme for analysis.

3.4 Data analysis

3.4.1 Hydrology

Quattro-Pro was used to analyse runoff data for the Skoenmakers River. Pre-1987 flow data was compared to post-1987 data in order to indicate the influence of the completion of the De Mistkraal Dam on streamflow in the Skoenmakers River. Flow duration curves were also constructed from the monthly runoff data. These curves display the relationship between streamflow and the percentage of the time a certain discharge is exceeded.

3.4.2 Physical environment

Cross-sectional data was downloaded directly from the total station into the computer by means of the TopComm Version1.0 programme for Windows95. This programme converted the data for use in the spreadsheet software package Quattro Pro. The cross-sectional profile for each transect was constructed by analysis and manipulation of this data (Figure 3.4). These cross-sections were used to calculate the average with and depth of the channel, elevations above and distances away from the channel for each vegetation type.

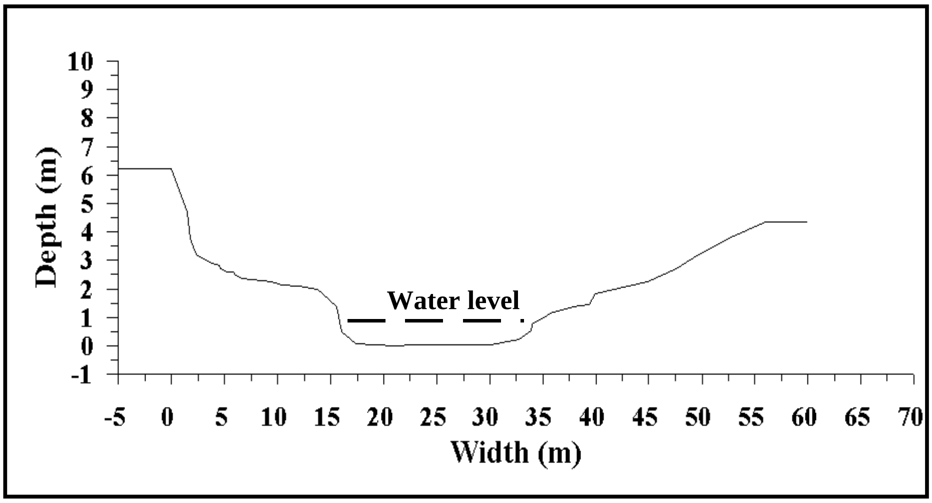

Figure 3.4: An example of a cross-section profile for the Skoenmakers River.

On-site observations and testing showed the dominant sediment type to be coarse gravel to sand size particles. Sediment samples taken from the different sites were therefore analysed using the dry sieving method (Gordon *et al.*, 1992:200) as it is the most commonly used method for the analyses of sand-sized particles. Results of this sediment sample analysis was classified according to the Udden-Wentworth scale (Blatt *et al.*, 1980) into the following sediment classes or types:

- Very coarse gravel (VCG) - clast size = 35 to 64 mm
- Coarse gravel (CG) - clast size = 16 to 35 mm
- Medium gravel (MG) - clast size = 8 to 16 mm
- Fine gravel (FG) - clast size = 2 to 8 mm
- Very coarse sand (VCS) - clast size = 1 to 2 mm
- Coarse sand (CS) - clast size = 0.5 to 1 mm
- Medium sand (MS) - clast size = 0.25 to 0.5 mm
- Fine sand (FS) - clast size = 0.125 to 0.25 mm
- Very fine sand (VFS) - clast size = less than 0.125 mm but coarser than silt
- Silt/clay (Si) - clast size = less than 0.125 mm

Data derived from this analysis and classification was fed into Quattro Pro and bar graphs (histograms) were constructed for the sediment samples of the individual morphological units at each site.

3.4.3 Riparian vegetation

"Spatial distribution patterns derived from relationships with the physical environment are essentially descriptive" (Van Coller, 1992:2). Qualitative (descriptive) data was compared to and integrated into the quantitative data derived from the plot sampling.

All the quantitative data from the plot sampling were fed into the Quattro Pro spreadsheet programme and the analysis of this data followed the methods described by Brower *et al.* (1990) and Kent and Coker (1992). The total area sampled for each species was calculated as well as the number of individuals for each species at each site for both the Skoenmakers and Volkers Rivers. These totals were used to calculate the following attributes for the vegetation communities (Brower *et al.*, 1990):

(a) *Density* (D) is the number of individuals in a unit area:

$$D_i = n_i / A \tag{1}$$

where D_i is the density for the species i, n_i is the total number of individuals counted for the species and A is the total area sampled.

(b) *Relative density (RD)* is the number of individuals of a given species (n_i) as a proportion of the total number of individuals of all species (Σn):

$$RD_i = n_i / \Sigma n \tag{2}$$

(c) *Frequency (f)* is the chance of finding a given species within a sample:

$$f_i = j_i / k \tag{3}$$

where f_i is the frequency of species i, j_i is the number of samples in which species i occurs, and k is the total number of samples taken.

(d) *Relative frequency (Rf)* is the frequency of a given species f_i as a proportion of the of the frequencies for all species (Σf):

$$\mathrm{R}f_i = f_i / \Sigma f_i \tag{4}$$

(e) *Coverage (C)* is the proportion of the ground covered by the aerial parts of the plant:

$$C_i = a_i / A_i \tag{5}$$

where a_i is the total area covered by species i (estimated from the foliage area), and A is the total habitat area sampled.

(f) *Relative coverage (RC_i)* is the coverage for species i (C_i) expressed as a proportion of the total coverage (TC) for all species:

$$RC_i = C_i / TC = C_i / \Sigma C_i \tag{6}$$

where ΣC_i is the sum of the coverages of all the species.

An index called the *importance value* (IV_i) is calculated from the sum of the above three relative measures for species i:

$$IV_i = RD_i + Rf_i + RC_i \tag{7}$$

This value for IV_i may range from zero to three (or 300%). Dividing IV_i by three results in a figure between zero and one (100%). This is referred to as the *importance percentage* which gives an overall estimate of the influence or importance of a plant species in the community. Figure 4.26 presents the importance percentages for the riparian species of the regulated river.

The percentage cover and position of each species along the transect were used to construct belt transect graphs in Quattro Pro. Soil analysis results were compared with these belt transects to indicate the relationship between these two components. The same method was use to compare cross-sectional data with the vegetation data (belt transects) for an indication of the distribution of vegetation types along the lateral vegetation gradient for both rivers. Comparisons were also made between the regulated river (Skoenmakers River) and the natural river (Volkers River) for each of these relationships. This resulted in an indication of the influence of the IBT on the river system's vegetation distribution and diversity.

3.4.4 Temporal changes

The impact of the IBT over time was assessed by means of aerial photo analysis. Five sets of photographs were obtained from The Chief Directorate: Mapping and Surveying at Mowbray, Cape Town. These include aerial photos for the pre-IBT phase (1960 and 1966) and the post-IBT phase (1978, 1987 and 1990). Analysis of these aerial photographs included measurements of the riparian zone width, as well as the channel width and channel position for each site before and after the completion of the IBT. Landuse changes were also recorded and compared for the two periods (See Figures 4.29 to 4.31).

Chapter 4: Results

4.1 Introduction

The first part of this chapter (Section 4.2) deals with the results obtained from the analysis of the runoff data for the regulated river (Skoenmakers River). The second part (Section 4.3) deals specifically with the response of the geomorphology of the Skoenmakers River to the Orange-Fish-Sundays River Interbasin Transfer Scheme. Changes in the geomorphological processes operating in the river system will be addressed. These results will include data from the cross-sectional surveys and field observations for both the Skoenmakers and Volkers Rivers. An analysis of aerial photographs for the period 1961 to 1990 were used to show the temporal changes of the IBT in the Skoenmakers River system.

The third part of the chapter (Section 4.4) deals more specifically with the distribution of the riparian vegetation and the interrelationships with the river morphology. Data obtained from plot sampling and the resulting belt transects were used to present results for this part of the chapter. Aerial and other photographs were used as an additional source for this information. Finally, part four (Section 4.5) will deal with the response of the riparian vegetation (the processes and structure) to the changes brought about by the IBT.

4.2 Hydrological changes

The hydrological regime[5] of the Skoenmakers River has undergone dramatic changes since the completion of the IBT. The river was transformed from the typical ephemeral stream found in semi-arid regions to a much larger perennial river. The post-IBT phase of the river can be divided into two periods of distinctive changes in the hydrology of the river. The first period is from 1979 to the construction of De Mistkraal Dam in 1985, and the second period follows the completion of De Mistkraal Dam up to the present.

Figure 4.1 represent the simulated natural flows for the Skoenmakers River and Volkers River catchment (Water Research Commission, 1997). It is evident from this plot that flood events of high magnitude (30 cumecs or more) probably occur in this system approximately every nine to ten years. These events are important in the channel forming processes of an ephemeral system.

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[5] "The *regime* of a river refers to its seasonal pattern of flow over the year." (Gordon *et al.*, 1992:121).

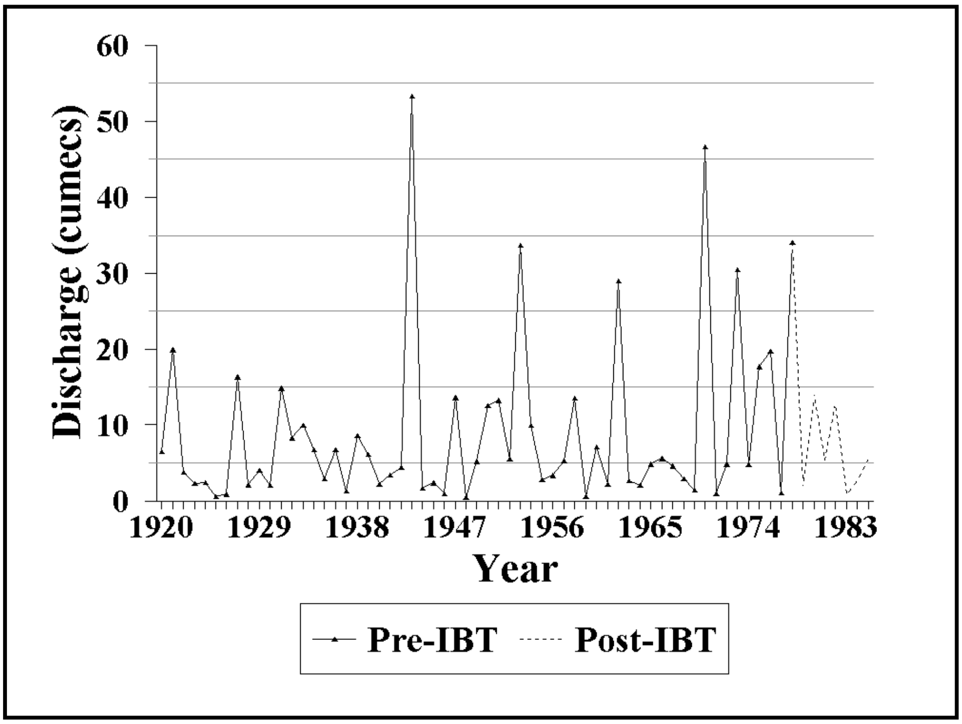

Figure 4.1: Simulated natural maximum daily flows (cumecs) for the Skoenmakers and Volkers River catchment for the period 1920 to 1985 (Water Research Commission, 1997).

The change in the hydrological regime of the regulated Skoenmakers River from an ephemeral to a perennial river also involved a change from a flood dominated system to a baseflow dominated system with a constant base flow throughout the length of the system. It can be assumed this post-IBT baseflow is much higher than the natural flood flows at the top of the Skoenmakers River system. Lower down the system, as catchment area and channel network length increases, the post-IBT baseflow is much lower than the natural flows generated by the flood events in the catchment.

Flow duration curves (Figure 4.2) were constructed for the Skoenmakers River based on data from the gauging station below the junction of the Skoenmakers and Volkers Rivers (pre-1985) as well as releases from De Mistkraal Dam (post-1985). All discharge values were calculated from the average monthly discharge in cubic metres per second (cumecs).

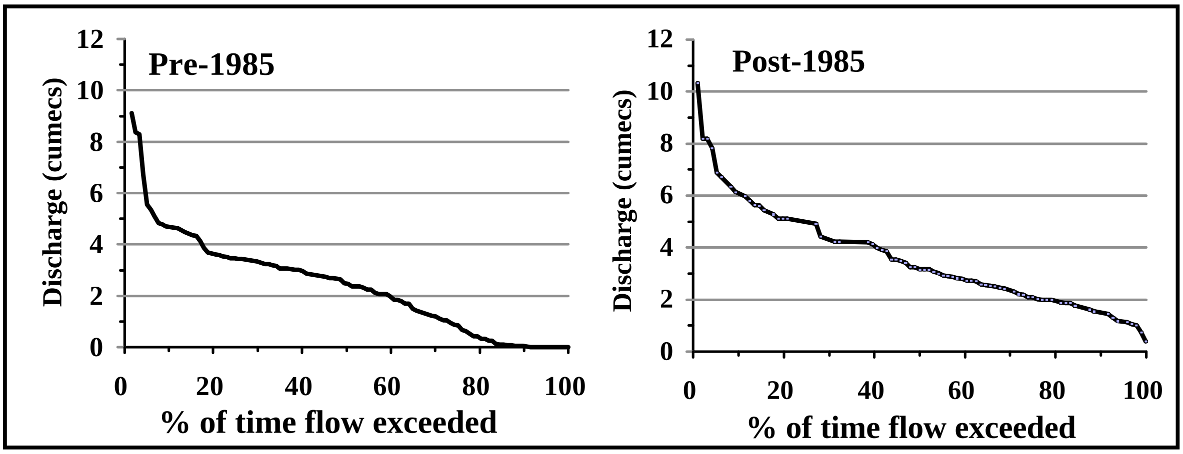

Figure 4.2: Monthly flow duration curves for the Skoenmakers River for the period 1981 to 1997 (Source: Department of Water Affairs and Forestry: Somerset East).

It is evident from these curves that De Mistkraal Dam had an influence on the hydrology of the Skoenmakers River system. Before the completion of the dam very low flows as well as periods of no flow conditions occurred for approximately 20% of the time whilst these flow conditions are absent from the data for the post-1985 curve. Although the dam had no significant influence on the mean flow (approximately three cumecs), flows that exceed this mean flow now occur 50% of the time in comparison to approximately 30% for the pre-1985 period. High flows (five cumecs and more) occur approximately 20 to 25% of the time in comparison to approximately 5% before the completion of the dam.

Figure 4.3 presents the increase in the average monthly discharge for the Skoenmakers River during the summer months after the completion of De Mistkraal Dam to an average of between four and six cubic metres per second. During May and June the releases from the dam into the Skoenmakers Canal are cut off for repair work to the canal, hence the decrease in runoff for this period.

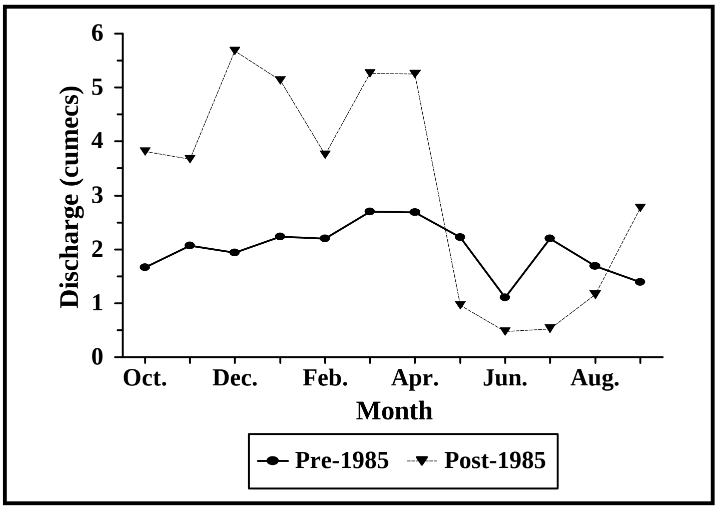

Figure 4.3: Average monthly runoff for the Skoenmakers River before (1978-1984) and after (1986, 1987) construction of De Mistkraal Dam (Source: Department of Water Affairs and Forestry, Cradock).

It is evident from Figure 4.3 that De Mistkraal Dam has led to a more distinct seasonal pattern of flow for the Skoenmakers River. This is an important factor as riparian vegetation needs an efficient seasonal flow to maintain its structure. The change in the Skoenmakers River's flow regime to a seasonal flow pattern also had an influence on the sediment sorting processes of the system and, therefore, on the geomorphology of the river.

4.3 IBT influence on the geomorphology

4.3.1 Changes in geometry

A comparison of cross-section profiles for the regulated and non-regulated rivers shows that the IBT had a more serious effect on the upper reaches of the Skoenmakers River. The pre-IBT channel was formed by infrequent floods that would increase with catchment area and channel network length. The post-IBT channel is now formed by the constant baseflows. The severe erosion and incision occurring in the upper reaches can therefore be related to the increased baseflow which is higher than the natural flood flows at the top of the system. A comparison of cross-sectional profiles of the regulated and non-regulated rivers clearly indicates this change in channel form. One representative cross-section for each river section (upper, middle and lower reaches) has been chosen to present the results. The full set of cross-sectional profiles can be seen in Appendix 1.

Under natural conditions, two sites at equal distances downstream for two different rivers with similar catchment conditions, like the Skoenmakers and Volkers Rivers, should have similar cross-section profiles. Such a comparison was made of two sites in the upper section of the two rivers approximately 500m below the point of IBT inflow for the Skoenmakers River and at the same distance downstream for the Volkers River (Figure 4.4).

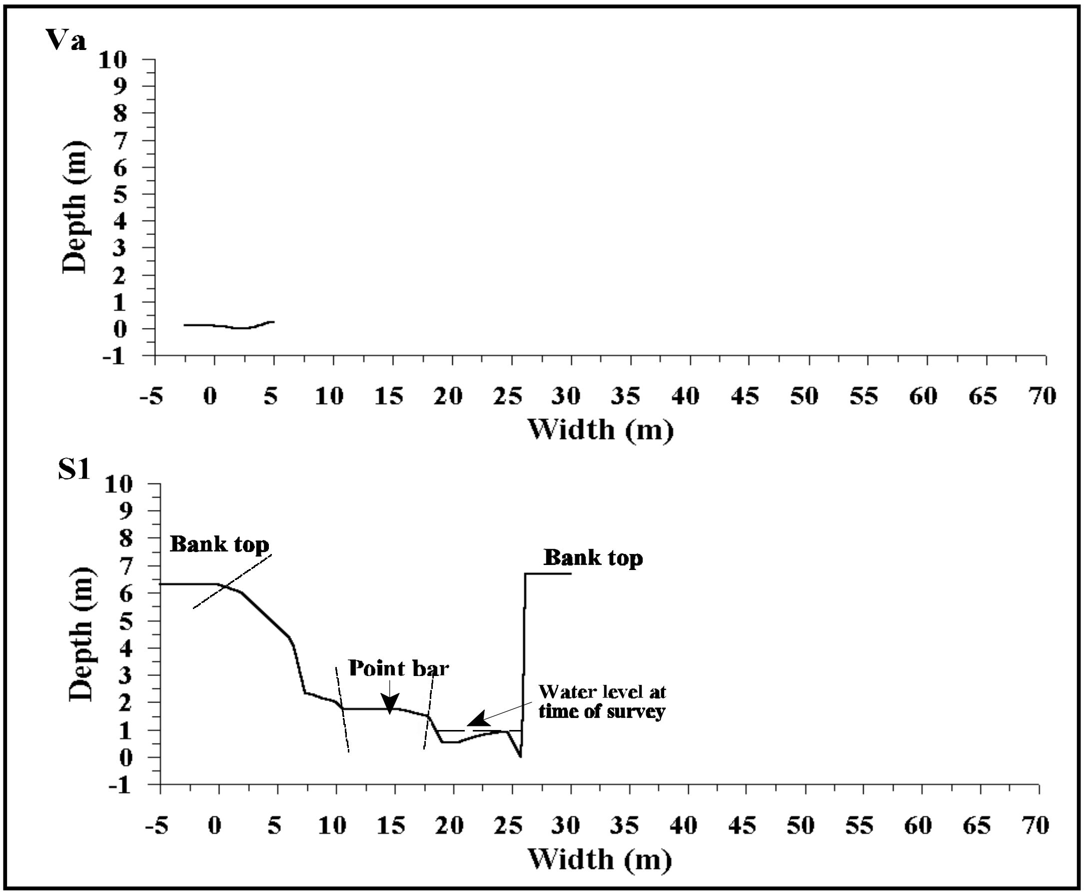

Figure 4.4: Comparison of two cross-sectional profiles for the upper reaches of the Volkers (Va) and Skoenmakers River (S1) immediately below the point of inflow of the IBT.

This comparison between the geometry of the unregulated river and that of the regulated river clearly shows that the IBT had a severe impact on the cross-sectional profile of the Skoenmakers River below the inlet of the IBT. Severe bank erosion has led to an increase of more than 300% in the average macro-channel width of the channel when compared to a similar site at the same distance downstream on the unregulated Volkers River. Incision of the regulated river's channel bed also led to an increased depth up to the point that the bedrock had been exposed. Incision and undercutting of the riverbanks in this area are quite severe and therefore enhance bank collapse and sediment input into the river. Observations in the field confirm the instability of the bank in this area which are contributed to by the weight of the trees (*Acacia karroo*) at the top of the banks. More detailed results on the interactions between the geomorphology and riparian vegetation will be presented in Section 4.4.

A comparison of two similar sites approximately 10 km downstream from the sites in Figure 4.4 and still in the upper reaches of the two rivers, shows that the impact of the IBT was still serious in this area but less severe (Figure 4.5). The degree of erosion and incision decreased significantly for this area and therefore the difference in the width and depth of the channel between these two sites is not as prominent as for sites S1 and Va.

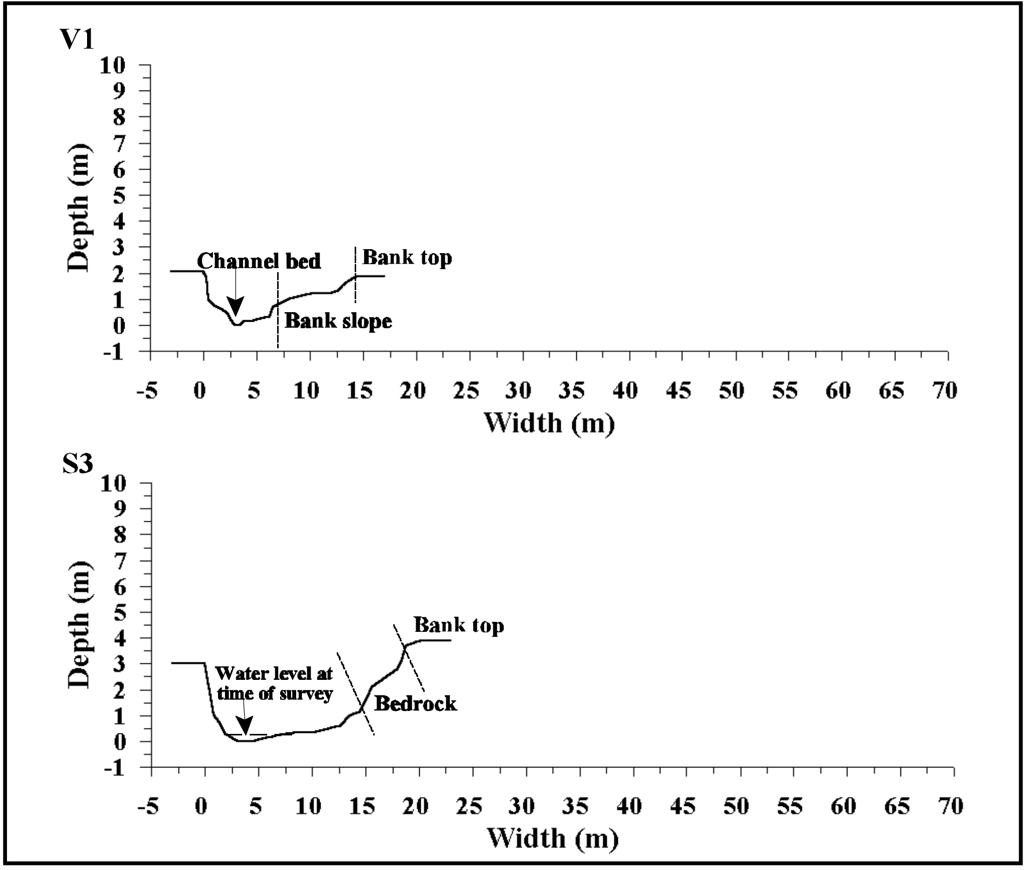

Figure 4.5: Comparison of two cross-sectional profiles for the upper reaches of the Volkers (V1) and Skoenmakers River (S3) approximately 10 km below the point of inflow of the IBT.

The bedrock intrusion on the right-hand side of site S3 stabilises the right-hand bank and field observations indicated that deposition of finer sediment between the cracks of the dolerite rocks are contributed to. The left-hand bank of site S3 is well-vegetated with grass species and therefore more stable than site S1 where the grass cover is sparse and the bank slopes are too steep for establishment of these species (See Section 4.4.1).

An increase in both the width and the depth of the channel is still evident in the middle reaches of the regulated river when compared to the non-regulated Volkers River (Figure 4.6). The impact of the IBT on the geometry in this section of the regulated river (approximately 25 km downstream) is less severe in comparison to the upper reaches as the banks become more stable.

The cross-sectional profile of site S6 is clearly more diverse in terms of the type of morphological units present when compared to the non-regulated Volkers River (V3).

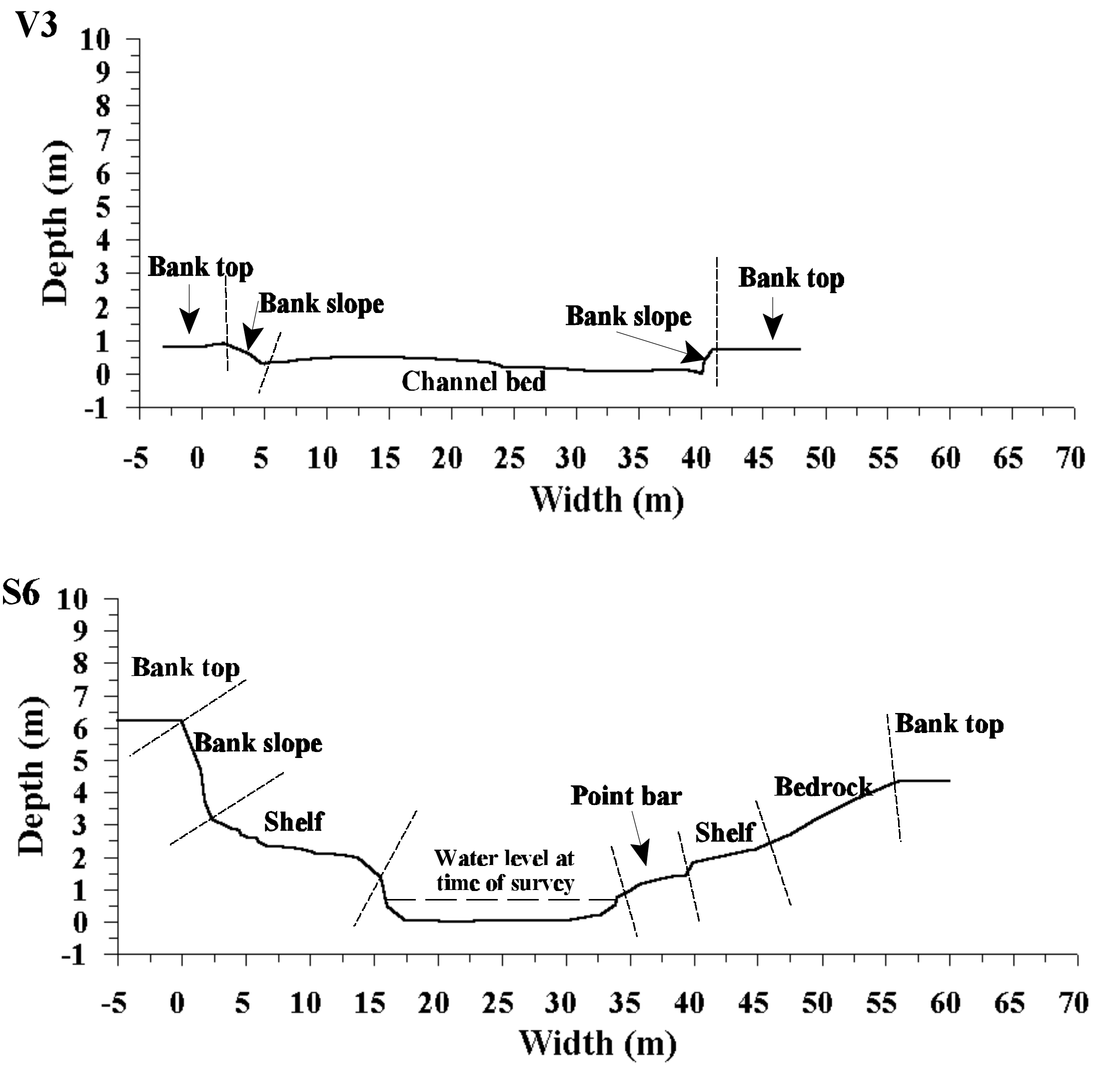

Figure 4.6: Comparison of two cross-sectional profiles for the middle reaches of the Volkers (V3) and Skoenmakers River (S6) approximately 25 km below the point of inflow of the IBT.

The similarity of the cross-sectional profiles for two sites in the lower reaches of the Skoenmakers and Volkers Rivers is evident from Figure 4.7. Similar morphological units such as mid-channel bars, etc. are evident from the cross-sectional profiles of both the regulated and non-regulated rivers. It is evident from Figure 4.7 that there is no significant difference between the width and depth of the two channels at this distance downstream.

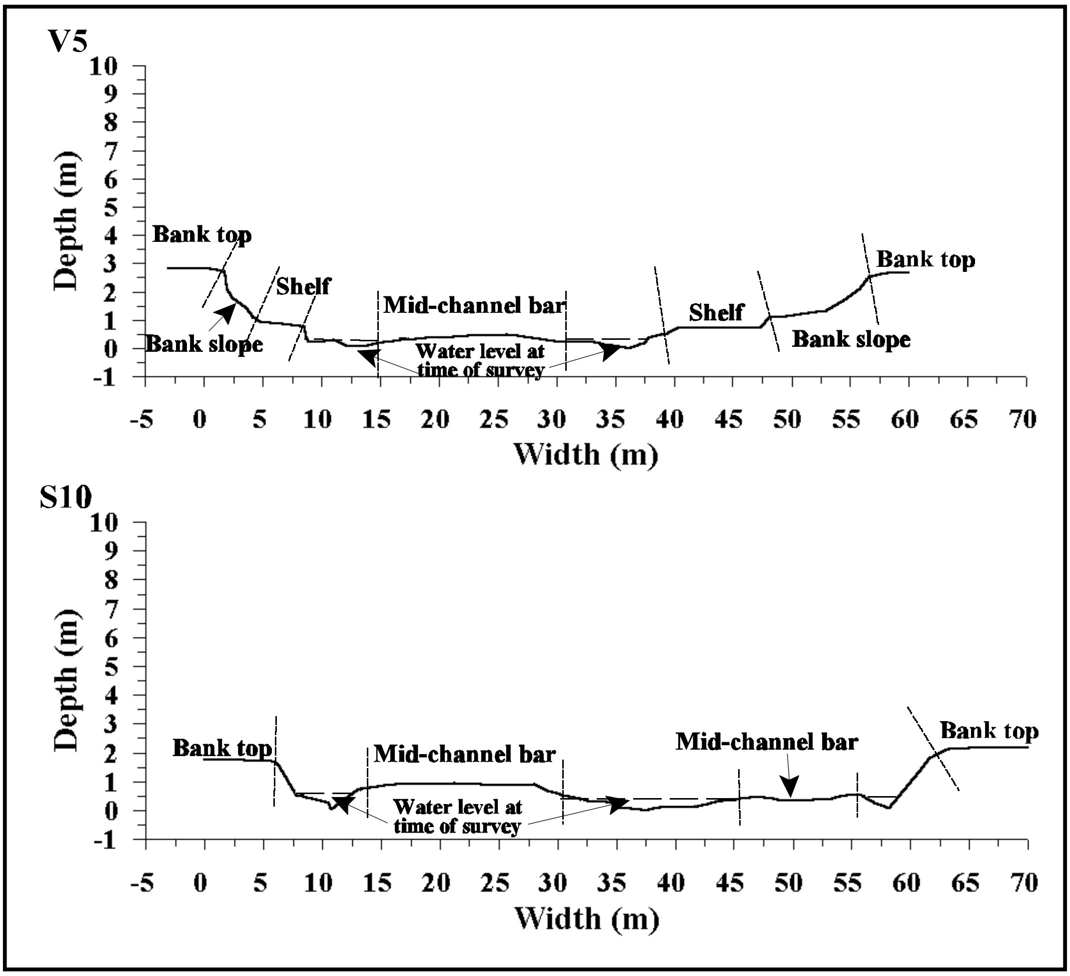

Figure 4.7 Comparison of two cross-sectional profiles for the lower reaches of the Volkers (V5) and Skoenmakers River (S10) approximately 40 km downstream for both rivers.

An analysis of the downstream changes in geometry of the same sites in Figures 4.4 to 4.7 is presented by Figure 4.8 which shows the steady decrease in the depth downstream for the regulated river. The non-regulated Volkers River shows an increase in depth from the upper to middle reaches and then remains constant. An increase of the bank top width in a downstream direction was evident for both rivers.

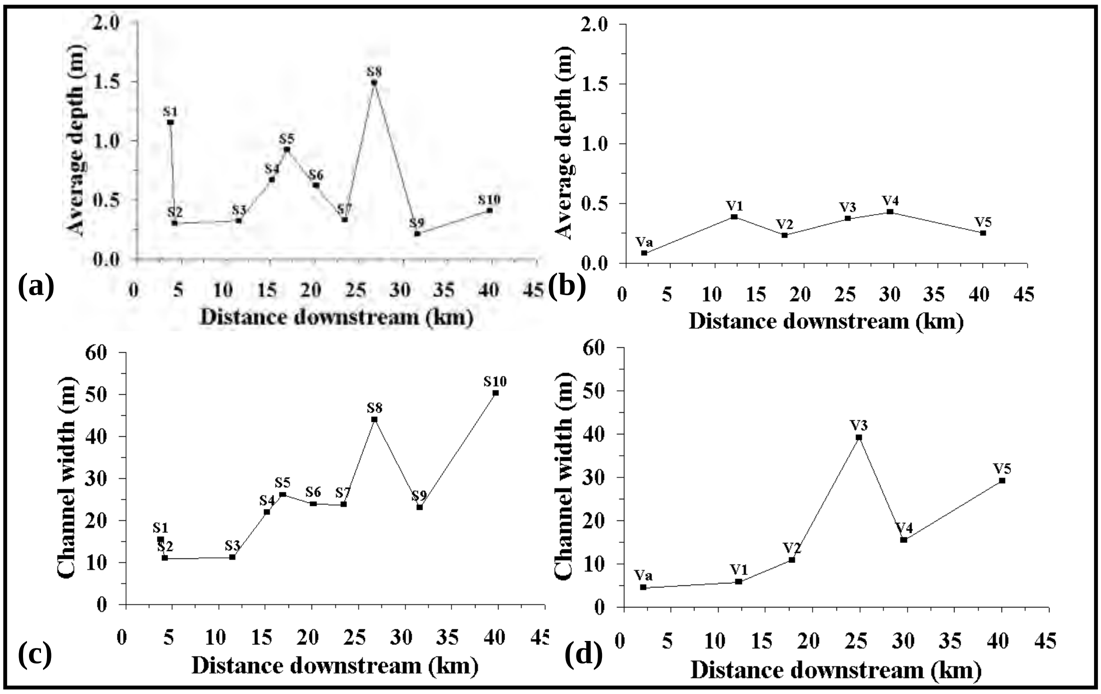

Figure 4.8: Downstream changes in the(a) depth and (c) width for the Skoenmakers River and (b) depth and (d) width for the Volkers River.

A steady increase in both width and depth is evident from the first site in the upper reaches of the non-regulated river (Va) to the next site (V1). The scenario is much different for the regulated river where a much higher value was recorded for both width and depth at Site S1 in comparison to the next two sites (S2 and S3), farther downstream in the upper reaches. This indicates that severe impact of the IBT on the geometry of the regulated river below the IBT inlet. The high value recorded for the width of the Skoenmakers River (S1) of almost 20 metres in comparison to the five metres recorded at Site Va along the Volkers River underline the severe erosion of the banks at Site S1.

An average depth of approximately 1.25 metres was recorded at Site S1. In comparison, an average depth of approximately 0.25 metres was recorded for Site Va at the same distance downstream along the non-regulated Volkers River. This supports field observations of the high degree of incision below the IBT inlet into the Skoenmakers River and was confirmed from conversations with local farmers in this area. A lower value for the depth of the regulated river was recorded at Site S10 in comparison to Site V5 of the non-regulated river. This is due to the higher degree of sediment deposition in the regulated river's lower reaches when compared to the Volkers River.

Surveyors' data from 1970 (*pre-IBT* phase) compared to the data obtained from cross-sectional surveys for this study (*post-IBT* phase) indicate the increase in the bank top width of the Skoenmakers River over the 20-year period since the completion of the IBT (Figure 4.9). The decrease in width for Site S7 from the pre-IBT to the post-IBT phase is due to enhanced deposition of the sediment produced at the top of the system through severe erosion. Site S6 to S7 presents the transitional zone for the middle to lower reaches and therefore higher degrees of deposition will be expected in this section of the river (natural or regulated).

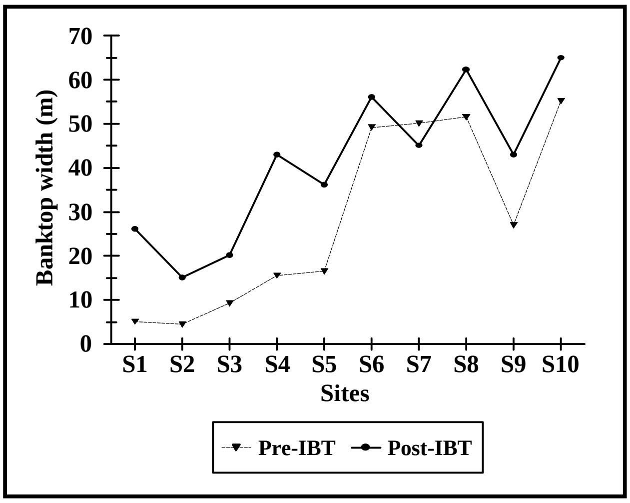

Figure 4.9: Comparison of the average bank top widths for the pre-IBT and post-IBT phases in the Skoenmakers River.

The narrower channel at Site S9 for both the pre- and post-IBT phases can possibly be explained by an increase in the density of the riparian vegetation. Analysis of aerial photographs for this area showed a significant increase in the width of the riparian vegetation zone and the density of the vegetation on the river banks.

It must be emphasised that the Skoenmakers River is part of a drainage network and should therefore be considered in relation to the tributaries, especially the pre-IBT channel. The sudden increase in the width of the Skoenmakers River's channel from Site S5 to Site S6 for the pre-IBT phase can probably be explained by the large tributary which joins the main channel at this point in the system (See Figure 1.3). A change in the geology from the Fort Beaufort to the Ecca Group of the Karoo Sequence (See Figure 1.6) was also recorded between these two sites which also contributes to sudden changes in the channel form.

4.3.2 Changes to the river banks

The morphological unit was used as spatial scale for the assessment of the bank conditions. The different morphological units considered to represent the channel banks is presented by Figure 4.10 and include the flood plain, bank top, bank's edge, bank slope and shelf. Sediment samples were taken for all of these units except the flood plain.

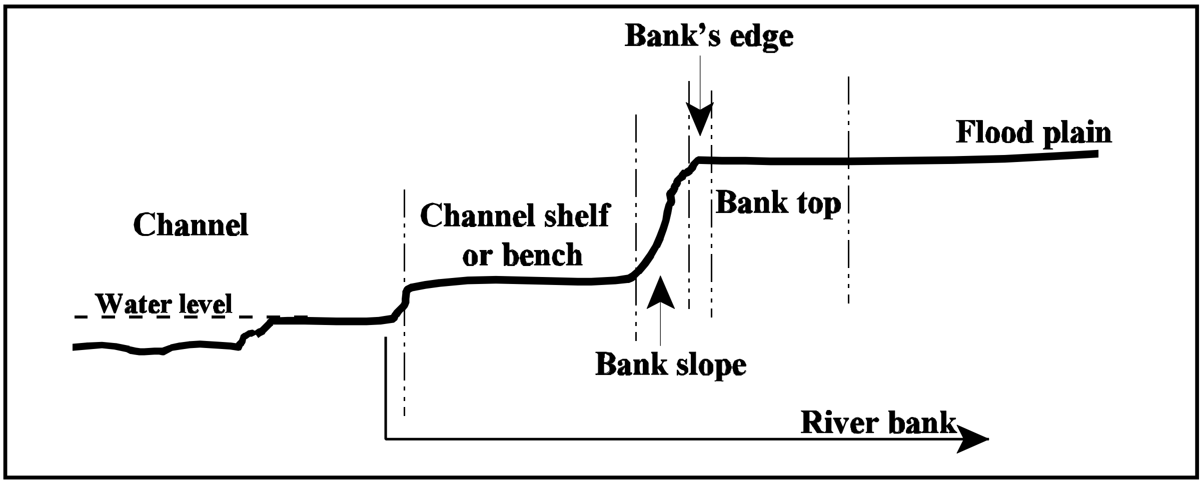

Figure 4.10: Types of morphological units presenting the channel banks.

Field observations of the bank condition were recorded onto data sheets and the data were compared to the quantitative data derived from the cross-sections. An assessment of the changes to the banks of the regulated river as a response to the IBT was made in terms of the bank condition (stable, degree of erosion and/or deposition), bank geometry (presence of shelves) and bank material.

These observations confirm the influence of the IBT on the bank condition of the Skoenmakers River. Severe bank erosion is evident, especially in the upper reaches of the river, much more so than for the upper reaches of the Volkers River. This can be linked to the change in the hydrological regime to baseflows which are higher than the natural flows generated by flood events. These events were responsible for the morphology of the pre-IBT channel of the Skoenmakers River and that of the Volkers River.

Plates 4.1 and 4.2 represent a section of river approximately three kilometres below the point of inflow just above site S1 along the Skoenmakers River. The severe erosion of the banks on either side is evident. Active undercutting is evident on the right-hand bank which leads to enhanced instability of the banks. Although erosion was also observed in the upper reaches of the Volkers River, little or no undercutting was observed. The upper reaches of the Skoenmakers River, on the other hand, has undergone severe undercutting. This process can be seen in the right-hand corner of Plate 4.2. This process leads to bank collapse and contributes to sediment input into the channel and to the middle and bottom of the banks.

Plate 4.1: Severe erosion and active undercutting of the right-hand bank evident for the upper reaches of the Skoenmakers River (approximately 3 km below the IBT inlet).

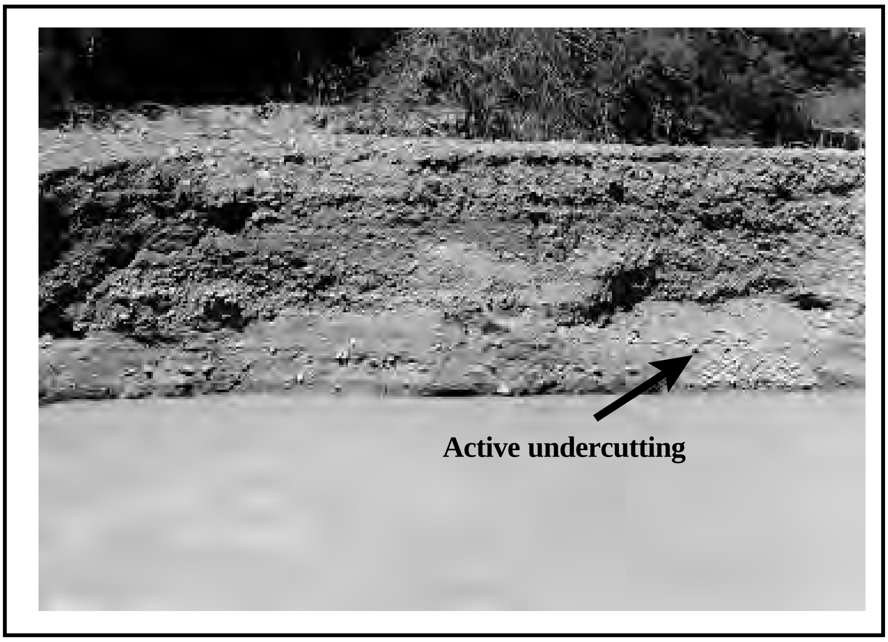

Plate 4.2: Stratified lefthand bank for same site as Plate 4.1.

The classification of the sediment samples for each of the sixteen representative sites was based on the Ubben-Wentworth scale (Blatt *et al.*, 1980). Histograms were used to display the sedimentological data derived from this classification (See Appendix 3). The following ten sediment classes or types were identified: Very coarse gravel (VCG), coarse gravel (CG), medium gravel (MG), fine gravel (FG), very coarse sand (VCS), coarse sand (CS), medium sand (MS), fine sand (FS), very fine sand (VFS) and silt/clay (Si).

A comparison of the sediment type for the banks of six sites representing the upper, middle and lower reaches of the Volkers and Skoenmakers Rivers is presented by Figures 4.11 to 4.13 respectively. The percentages for each sediment class were calculated from the average percentage of the two banks (left- and right-hand banks) including that of the shelves (if present).

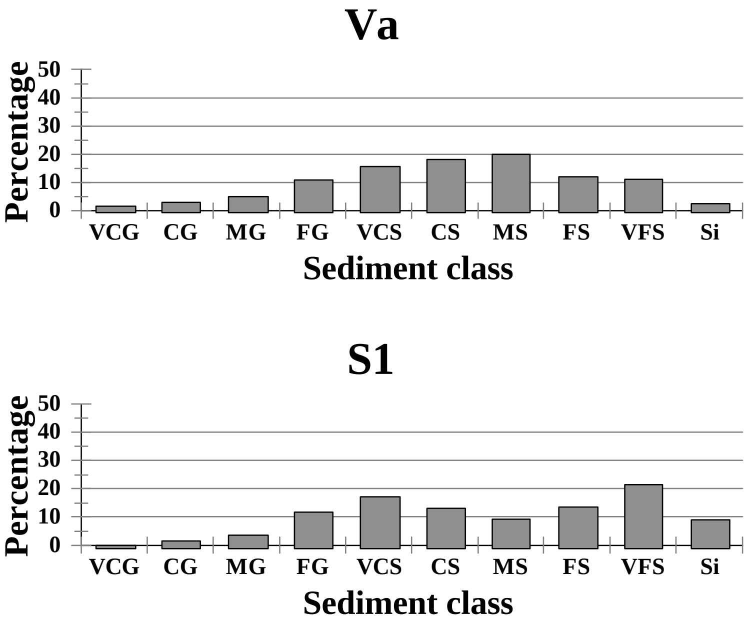

Figure 4.11: Bank sediment sample analysis for two sites at equal distances along the Volkers (Va) and Skoenmakers (S1) Rivers' upper reaches.

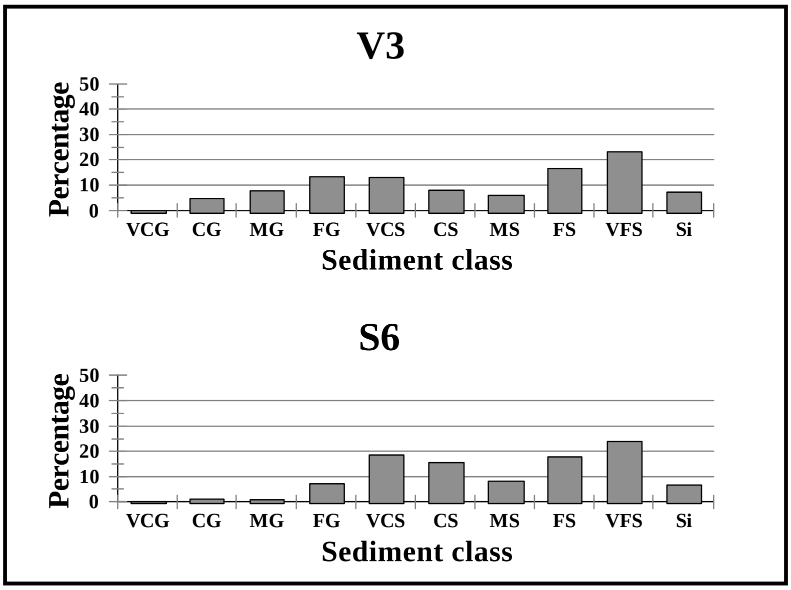

Figure 4.12: Bank sediment sample analysis for two sites at equal distances along the Volkers (V3) and Skoenmakers (S6) Rivers' middle reaches.

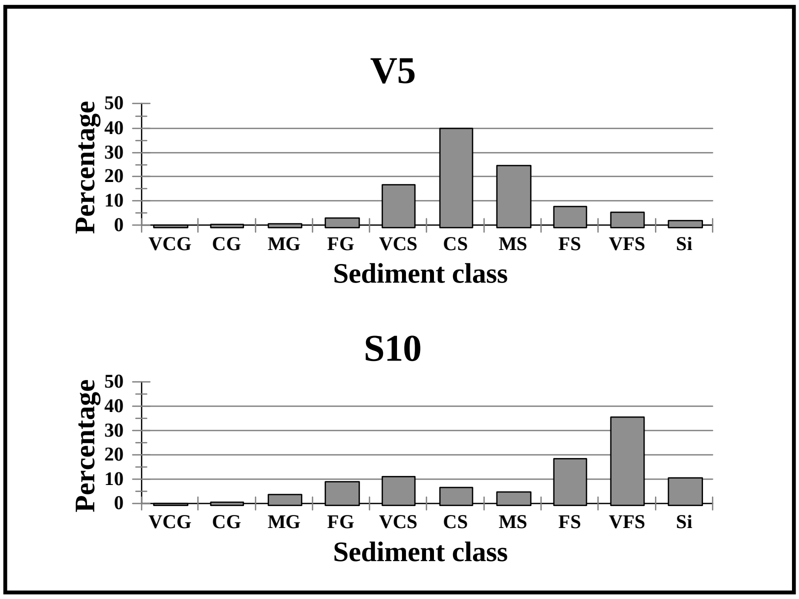

Figure 4.13: Bank sediment sample analysis for two sites at equal distances along the Volkers (V5) and Skoenmakers (S10) Rivers' lower reaches.

The upper and lower reaches of the Skoenmakers River show significant higher percentages of finer sediment for the banks when compared to similar regions in the Volkers River. The middle reaches of the two rivers shows similar sediment classes, tending towards sandy banks.

Table 4.1 present descriptive measures of the sediment size distribution for each site as calculated from the sediment analysis. The mean sediment size was calculated by means of the equation of Folk and Ward (Blatt *et al.*, 1980):

$$M_z = \frac{D_{16} + D_{50} + D_{84}}{3} \qquad (8)$$

where D_{16}, D_{50} and D_{84} are the diameters of the sediment particles for the 16th, 50th and 84th percentiles respectively.

Table 4.1: Descriptive measures of the bank sediment size distribution for the river banks at each site along the Volkers and Skoenmakers Rivers.

VOLKERS RIVER					
Site	**Sediment size (ö value)**				**Sediment size class for mean sediment size**
	D_{16}	**D_{50}**	**D_{84}**	**Mean (M_z)**	
Va	-1.60	0.80	3.00	0.73	Very coarse sand / Coarse sand
V1	-1.00	1.75	3.00	1.25	Coarse sand / Medium sand
V2	0.00	2.35	3.60	1.98	Medium sand
V3	-1.85	1.20	3.65	1.00	Coarse sand
V4	0.85	2.15	3.45	2.15	Medium sand / Fine sand
V5	-0.25	0.70	2.00	0.82	Very coarse sand / Coarse sand
SKOENMAKERS RIVER					
Site	**Sediment size (ö value)**				**Sediment size class for mean sediment size**
	D_{16}	**D_{50}**	**D_{84}**	**Mean (M_z)**	
S1	-1.10	1.65	3.75	1.43	Coarse sand / Medium sand
S2	-0.85	1.60	3.75	1.50	Coarse sand / Medium sand
S3	-1.20	0.70	2.30	0.60	Very coarse sand / Coarse sand
S4	-1.00	1.00	2.50	0.83	Very coarse sand / Coarse sand
S5	0.70	2.25	3.50	2.15	Medium sand / Fine sand
S6	-0.60	2.00	3.65	1.68	Coarse sand / Medium sand
S7	0.80	2.50	3.60	2.30	Medium sand / Fine sand
S8	0.00	2.65	3.65	2.10	Medium sand / Fine sand
S9	1.37	2.87	3.70	2.65	Medium sand / Fine sand
S10	-0.90	2.75	3.80	1.88	Coarse sand / Medium sand

The average sediment size for each river was derived from the total of all the sediment samples taken for all the sites. It was evident from a comparison of these values (Figure 4.14) that the sediment for the Skoenmakers River shows overall lower values for the sediment sizes and therefore consists of finer sediment overall. The highest percentage values recorded for the sediment of the Skoenmakers River were for the sediment classes between medium sand and very fine sand. In comparison, the highest values for the Volkers River were between fine gravel and coarse sand. The percentage silt in the Skoenmakers River showed an increase of approximately 100% when compared to the Volkers River.

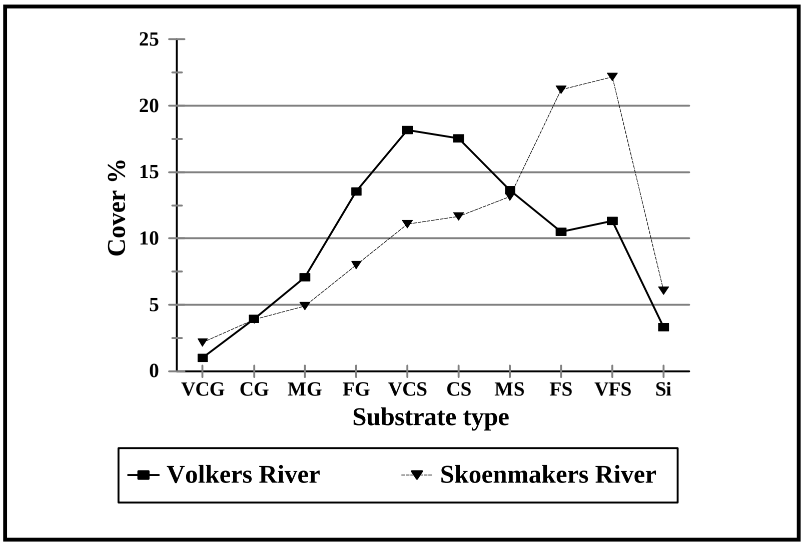

Figure 4.14: A comparison of the overall sediment size for the Volkers and Skoenmakers Rivers.

The impact of the IBT in the middle and lower reaches of the Skoenmakers River is less severe in terms of the degree of erosion, and higher degrees of bank accretion were observed for these areas. Point bars were formed in the Skoenmakers River but were absent in similar areas of the Volkers River. The most prominent difference in bank conditions for the Skoenmakers and Volkers Rivers can be seen in the formation of shelves. Table 4.2 present descriptive measures of the sediment size distribution for sediment samples taken from the sites where shelves were present.

Table 4.2: Descriptive measures of the shelf sediment size distribution along the Volkers and Skoenmakers Rivers.

River	**Site**	**Sediment size (ö value)**				**Sediment size class for mean sediment size**
		D_{16}	**D_{50}**	**D_{84}**	**Mean (M_z)**	
Volkers River	V5	-2.25	-0.35	2.50	-0.03	Fine gravel / Very coarse sand
Skoenmakers River	S4	-2.75	0.10	2.10	-0.18	Fine gravel / Very coarse sand
Skoenmakers River	S5	-2.55	-0.25	2.85	0.02	Very coarse sand
Skoenmakers River	S6	-2.35	-0.35	3.10	0.13	Very coarse sand / Coarse sand
Skoenmakers River	S7	-2.70	-0.20	2.95	0.02	Very coarse sand
Skoenmakers River	S9	-2.15	0.21	2.75	0.27	Very coarse sand / Coarse sand
Skoenmakers River	S10	-2.25	0.37	2.35	0.16	Very coarse sand / Coarse sand

Sediment supply was found to be the main variable changing in a downstream direction. Sediment supply in the upper reaches of the regulated river was greatly enhanced due to the erosive force of the additional water flowing into a once ephemeral stream. Channel bed aggradation was also contributed to in the lower reaches the regulated river's system The sediment sorting processes were found to be more defined for the regulated river when compared to the non-regulated river. A distinctive sorting of particle sizes from coarser material in the upper reaches to finer sediment sizes lower down the system was observed for the Skoenmakers River in comparison to the gravel and/or sand deposits of the Volkers River's channel bed (See Table 4.4).

A qualitative assessment of the bank conditions for three representative sites along each of the two rivers (Table 4.3) shows the absence of shelves in the middle reaches of the Volkers River (Site V3). In comparison, well-developed shelves were formed at site S6 on the Skoenmakers River.

Table 4.3: Qualitative assessment of bank conditions, geometry and material for the Volkers and Skoenmakers Rivers.

LOCATION			BANK GEOMETRY	BANK CONDITION			BANK MATERIAL
Reach	**Site**	**Bank**	**Shelves present**	**Stable**	**Erosion**	**Deposition**	**Particle size**
VOLKERS RIVER							
1	Va	Right	No	Yes			Coarse Sand
		Left	No	Yes			Coarse Sand
1	V1	Right	No	Yes		Medium	Medium Sand
		Left	No		Low		Coarse Sand
2	V2	Right	Yes		Low		Medium Sand
		Left	No	Yes		Medium	Fine Sand and Bedrock
3	V3	Right	No		Low	Low	Coarse Sand
		Left	No	Yes		Medium	Coarse Sand
3	V4	Right	No		Low	Low	Fine Sand
		Left	No		Low	Medium	Medium Sand, Fine Sand
4	V5	Right	Yes		Medium	High	Fine Sand, Coarse Sand, Silt
		Left	Yes	Yes		Medium	Coarse Sand, Very Coarse Sand
SKOENMAKERS RIVER							
1	S1	Right	No		Severe		Medium Sand, Coarse Sand
		Left	Yes		Medium		Fine Sand, Coarse Sand
1	S2	Right	No		Severe		Coarse Sand, Silt
		Left	Yes (Small)		Medium	Medium	Coarse Sand, Silt
2	S3	Right	No		Medium	Low	Coarse Sand, Bedrock
		Left	No		Low		Very Coarse Sand, Coarse Sand
2	S4	Right	Yes		Low	Low	Coarse Gravel, Cobble
		Left	No		Severe		Coarse Sand, Cobble
2	S5	Right	No		High		Clay, Fine Sand, Coarse Gravel
		Left	Yes			High	Clay, Fine Sand, Medium Sand
3	S6	Right	Yes			Medium	Coarse Sand
		Left	Yes			High	Medium Sand, Fine Sand
4	S7	Right	Yes		Low		Fine Sand
		Left	Yes			Medium	Medium Sand, Fine Sand
4	S8	Right	No		High		Medium Sand, Fine Sand
		Left	No		Medium		Fine Sand
4	S9	Right	Yes			High	Fine Sand
		Left	Yes		Low		Fine Sand
5	S10	Right	Yes		Low	Medium	Coarse Sand, Medium Sand
		Left	Yes			High	Coarse Sand, Bedrock

4.3.3 Changes to the river channel

A qualitative assessment was made for the channel changes in the Skoenmakers River that occurred as a response to the IBT based on the channel condition, channel geometry and channel (bed) material. This data was compared to data derived from the same assessment for the Volkers River and is presented in Table 4.4.

Table 4.4: Qualitative assessment of channel conditions for the Volkers and Skoenmakers Rivers.

SITE	**CHANNEL GEOMETRY**				**CHANNEL BED CONDITION**			**CHANNEL MATERIAL**
	Planform	**Pattern**	**Degradational or Aggradational**	**Morphological unit**	**Stable**	**Erosion**	**Deposition**	**Bed composition**
VOLKERS RIVER								
Va	Straight	Single	Aggradational				High	Medium sand
V1	Meander	Single	Aggradational				High	Coarse Sand
V2	Straight	Single	Aggradational				High	Coarse Gravel, Cobbles
V3	Meander	Single	Degradational				Medium	Coarse Sand, Coarse Gravel
V4	Straight	Single	Degradational			Low	Medium	Coarse Sand, Fine Gravel
V5	Straight	Braided	Aggradational	Mid-channel bar			High	Coarse Sand, Fine Gravel
SKOENMAKERS RIVER								
S1	Meander	Single	Degradational	Point bar		Severe		Cobble, Bedrock
S2	Meander	Single	Degradational	Point bar		High		Cobble, Coarse Sand, Silt
S3	Meander	Single	Degradational	Bedrock intrusion		High		Cobble
S4	Meander	Single	Degradational	Point bar		Severe		Cobble and Bedrock
S5	Straight	Single	Degradational	Point bar		Low	Low	Loose gravel
S6	Meander	Single	Degradational	Point bar		Low		Cobble, Coarse Gravel
S7	Meander	Single	Aggradational	Point bar		Low	Low	Cobble, Coarse Gravel, Fine Gravel
S8	Meander	Braided	Degradational	Mid-channel bar		Medium	High	Coarse Gravel, Cobble, Coarse Sand
S9	Meander	Single	Aggradational	Point bar		Medium		Coarse Gravel, Cobble, Bedrock
S10	Straight	Braided	Aggradational	Mid-channel bars (vegetated + unvegetated)			High	Silt, Fine Sand, Cobble, Coarse Gravel, Bedrock

At site Va the active channel of the ephemeral Volkers River was most difficult to distinguish from the rest of the surrounding environment. The only indication of the existence of a river channel was the riparian vegetation (*Acacia karroo*) which encroached the channel bed at this site. In comparison, the channel conditions at site S1 (about 500m below the IBT inlet on the Skoenmakers River) changed dramatically due to the IBT. Severe incision of the channel bed had occurred to such a degree that the bedrock has been exposed. The bed material therefore consists of mostly cobble and bedrock at this site whilst the bed material at site Va (at the same distance downstream on the Volkers River) was a mixture of fine to medium sand.

Lower down the Skoenmakers River, in the middle and lower reaches, it is evident from Table 4.4 that the impact of the IBT on the channel condition was much less severe. The only difference could be seen in the introduction of finer sediment into the Skoenmakers River's system which led to the formation of morphological units such as mid-channel bars which are absent or less prominent in the Volkers River's middle reaches.

The temporal change to the channel of the Skoenmakers River was assessed by means of aerial photo analysis for the pre- and post-IBT phases. A comparison of a set of *pre-IBT* (1960) and *pos-IBT* (1990) aerial photographs for a section of the upper reaches in the Skoenmakers River (Figure 4.15) clearly indicates this lateral shift in the planform of the river.

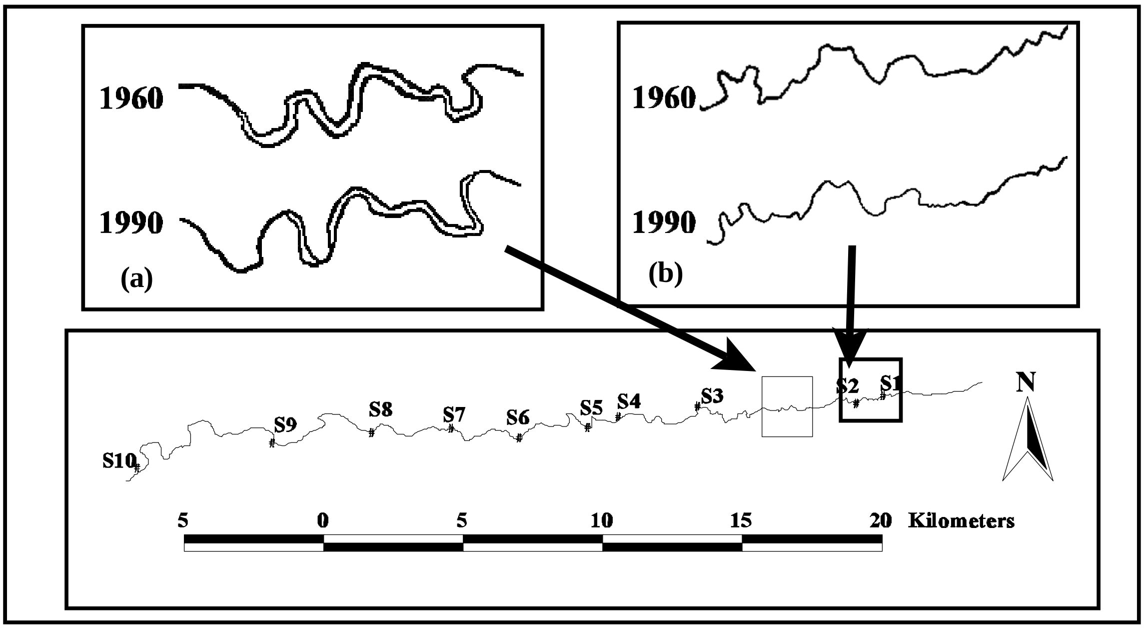

Figure 4.15: Shift in channel position for the upper reaches of the Skoenmakers River (1960) before and (1990) after the completion of the IBT.

Calculations from the comparison in Figure 4.15 indicated a change in the sinuosity of the

Skoenmakers River for the post-IBT phase. Sinuosity is most commonly measured by means of the sinuosity index (SI), given as (Gordon *et al.*, 1990:312):

$$SI = \frac{\text{Channel distance}}{\text{Downvalley distance}} \tag{8}$$

Therefore:

For (a):

$$SI_{1960} = \frac{2.12\text{km}}{1.20\text{km}} = 1.767$$

$$SI_{1990} = \frac{2.07\text{km}}{1.20\text{km}} = 1.725$$

For (b):

$$SI_{1960} = \frac{1.72\text{km}}{0.90\text{km}} = 1.911$$

$$SI_{1990} = \frac{1.53\text{km}}{0.90\text{km}} = 1.700$$

The impact of IBT is more severe higher up the Skoenmakers River system as a much greater difference between the SI values for the pre- and post-IBT phases is evident for this region (b) than in the case of (a) lower down the system.

Changes to the geomorphology of a river will have a significant impact on the riparian vegetation due to the mutual relationship between these two river components. It is therefore appropriate at this stage to look at the results for the data on these interrelationships and to indicate the specific interrelationships that exist before presenting results on the impact of the IBT on the riparian vegetation.

4.4 Interrelationships between riparian vegetation and geomorphology.

4.4.1 Spatial distribution of riparian vegetation

The average number of species for the three river sections (upper, middle and lower reaches) was calculated from the total number of species measured at each site within the different sections. The results from these calculations are presented by Figure 4.16. An increase in the number of species is evident from Figure 4.16 along the length of both the regulated and non-regulated rivers. This spatial distribution results in the longitudinal vegetation gradient (Van Coller, 1992).

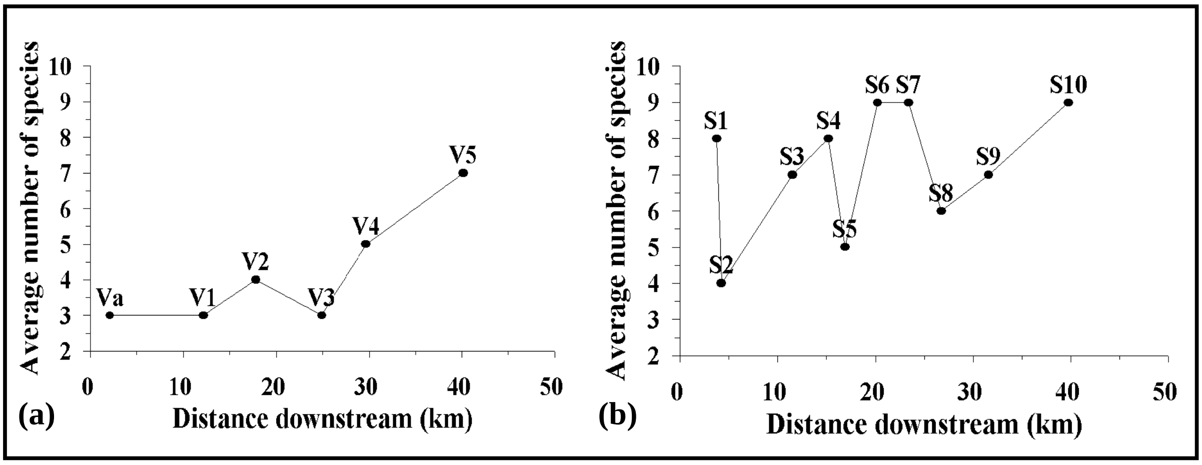

Figure 4.16: Downstream change in the number of riparian vegetation species for the Volkers River (a) and Skoenmakers River (b).

The lower values recorded at Sites S2, S5 and S8 of the Skoenmakers River can be explained by changes in the morphological diversity at these sites. The influence of the morphological diversity will be discussed in more detail under Section 4.4.2.

Riparian vegetation species distribution along the river is highly dependent upon the change in elevation above the water level (Van Coller, 1992). Results from plot sampling for the vegetation and cross-sectional surveys of the geomorphology strongly underlines this statement and therefore indicates an important relationship between the riparian vegetation and the geomorphology (Figure 4.17).

The lowest point on the cross-section for each site was used as the baseline for the calculation of the elevation values at each site for the bank top, the bank slope and in the channel (eg. mid-channel bars). The average elevation for the two rivers was then calculated from these values. Cover percentages were calculated from the average for each species of each vegetation type (See Table 4.5 for specific species) at each site for the two rivers.

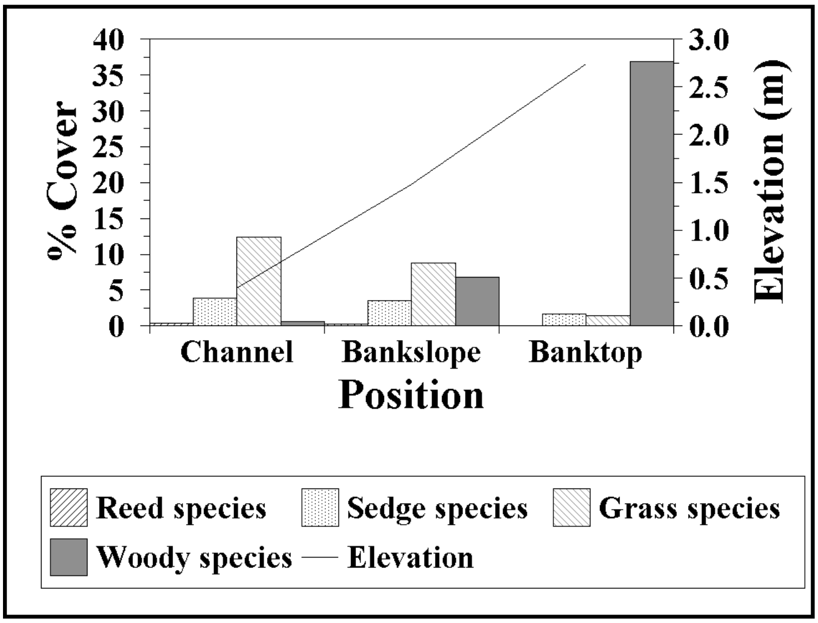

Figure 4.17: Relationship between the average elevation above the channel bed and vegetation type for the Volkers and Skoenmakers Rivers.

It is evident from these results that a specific sequence of riparian vegetation distribution exists based on the elevation above the active channel. Woody species showed a higher average cover percentage at higher altitudes whilst grass and sedge species were more abundant at lower elevations. This distribution was found to be closely related to the horizontal vegetation gradient identified by Van Coller (1992).

Table 4.5: Species grouping according to the different vegetation types.

Vegetation type	**Woody**	**Grass**	**Sedges**	**Reeds**
Species name	*Acacia karroo*	*Cynodon dactylon*	*Asclepias fruticosa*	*Phragmites mauritianus*
	Rhus lancea	*Pennisetum setaceum*	*Asparagus plumosus*	
	Lycium oxycarpum	Other grass species	*Cyperus dives*	
	Tamarix chenensis			
	Nicotiana glauca			
	Melianthus major			

Results from plot sampling were superimposed on the cross-sectional profiles for each site and belt transects for each site were constructed (Appendix 2). Two sites, representative of the lower reaches of the Skoenmakers and Volkers Rivers, were chosen for the purpose of presenting these results (Figure 4. 18).

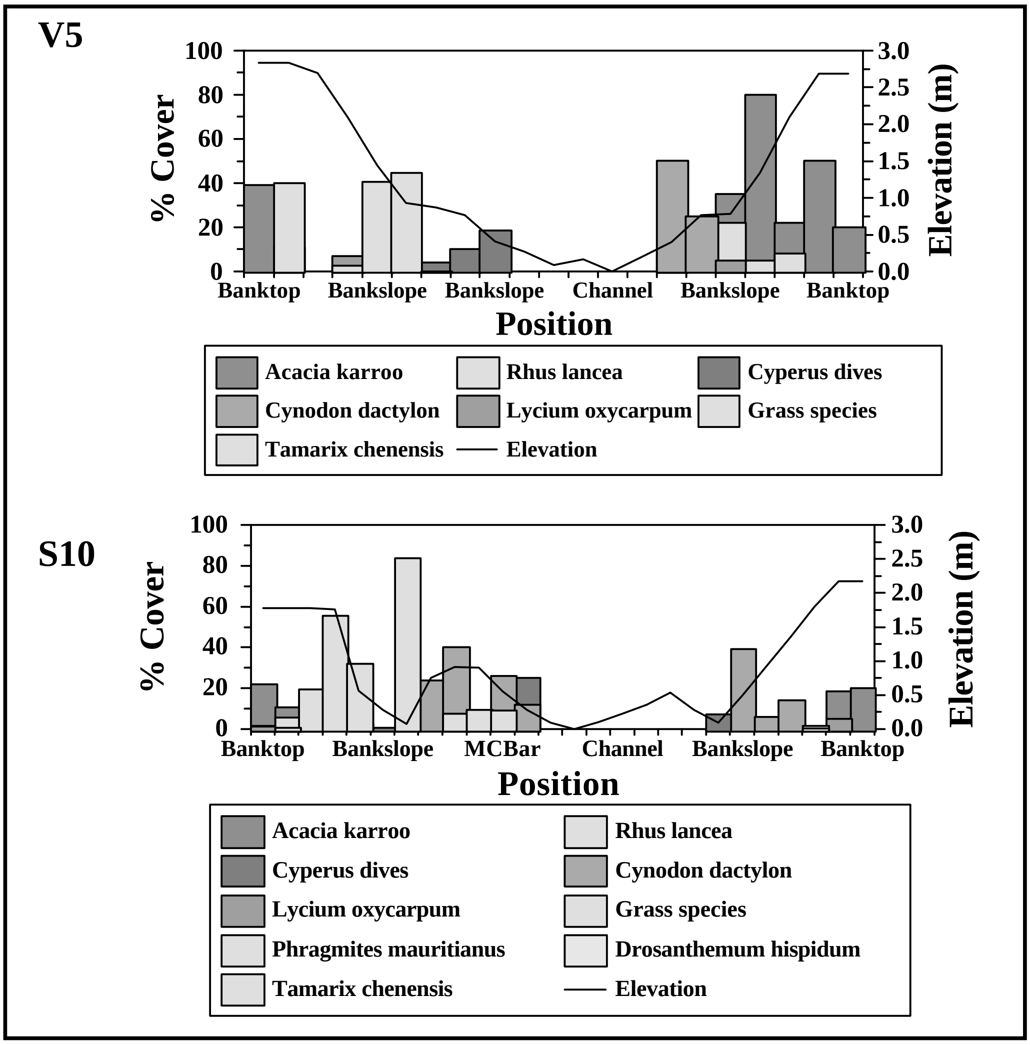

Figure 4.18: Belt transect of the riparian vegetation for two selected, representative sites in the lower reaches of the Volkers (V5) and Skoenmakers (S10) Rivers.

It is evident from Figure 4.18 that tree species (*Acacia karroo* and *Rhus lancea*) tend to be the dominant vegetation type farther away from the active channel. Closer to the active channel, on the bank slope and shelves, grass species become established along with juveniles of the woody species. The bottoms of the banks, the water's edge and channel bars (mid- and point bars) are dominated by sedge species (eg. *Cyprus dives*), reeds (*Phragmites mauritianus*) and grass species.

The influence of the geomorphology of the river is evident from the results presented above. It is important however to realise that a mutual relationship exists between vegetation and geomorphology and therefore the riparian vegetation distribution influences the morphology of the river as well. Results from sediment sample analysis indicated that vegetation enhances the deposition of finer sediment, eg. at site S10 of the Skoenmakers River higher percentages of the finer sediment classes (fine sand, very fine sand and silt) was recorded for the vegetated bar (Figure 4.19).

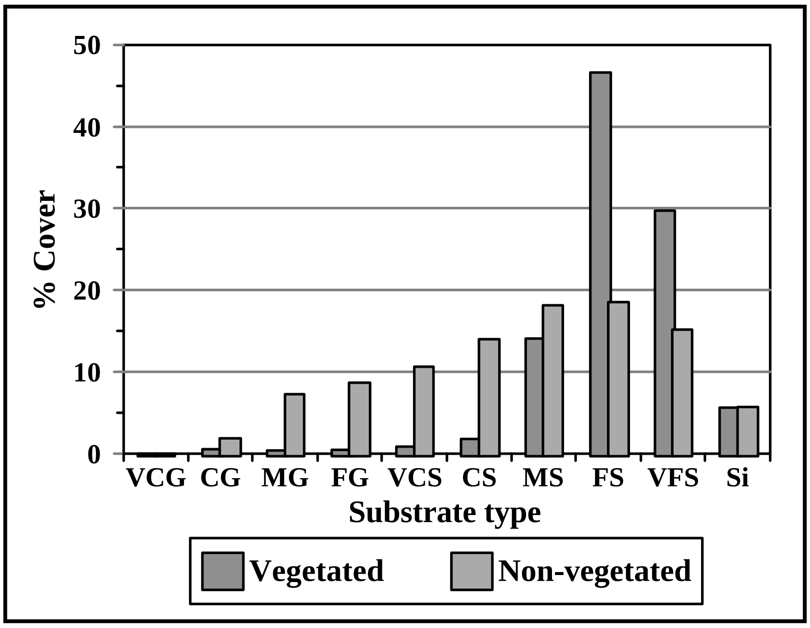

Figure 4.19: Sediment composition for a vegetated and non-vegetated mid-channel bar at site S10 of the Skoenmakers River.

Field observations and a qualitative assessment of banks stability indicated that attributes of the vegetation such as the health, age, type, density, etc. influences bank stability. It was observed that the *Acacia karroo* trees decreased the bank stability in the upper reaches of the Skoenmakers River below the IBT inlet. The weight of the trees resulted in bank collapse, especially in areas where undercutting of the banks occurred. Lower down the system it was found that the marginal vegetation (eg. sedge species) induced local deposition on banks by reducing near-bank flow velocities. It is therefore evident that these marginal vegetation types played a major role in controlling erosion of the river bed and banks. It was obvious from these observations that channel form of the river was greatly influenced by the binding effects of vegetation on banks and this, in turn, influenced the morphological diversity of the system.

4.4.2 Morphological diversity

Morphological diversity or heterogeneity was found to be a very important factor influencing the riparian vegetation distribution patterns and *vice versa*. This diversity is related to the number of morphological units at a specific site (Table 4.6), and from the results of the vegetational and geomorphological surveys it was evident that an important interrelationship exists between the number of morphological units and riparian vegetation species.

Table 4.6: Morphological diversity of the Volkers and Skoenmakers Rivers.

LOCATION		**MORPHOLOGICAL UNIT PRESENT**				
Site	**Distance downstream (km)**	**Bank slope**	**Shelf**	**Point bar**	**Mid-channel bar**	**Bedrock intrusion**
VOLKERS RIVER						
Va	3.51	**U**				
V1	12.20	**U**				
V2	17.83	**U**				**U**
V3	24.91	**U**				
V4	29.67	**U**				
V5	40.13	**U**	**U**	**U**	**U**	
SKOENMAKERS RIVER						
S1	3.79	Incised		**U**		
S2	4.27	**U**		**U**		
S3	11.52	**U**				**U**
S4	15.21	**U**	**U**	**U**		
S5	16.88	Incised	**U**	**U**		**U**
S6	20.21	**U**	**U**	**U**		**U**
S7	23.42	**U**	**U**			
S8	26.74	**U**			**U**	
S9	31.59	**U**	**U**		**U**	
S10	39.75	**U**	**U**		**U**	

An assessment of the relationship between the number of morphological units and number of species was done by means of a regression analysis for the Skoenmakers and Volkers Rivers (Table 4.7). The R squared value for the two rivers indicate a positive correlation between the number of morphological units and the number of species at each site and therefore the influence of the morphological heterogeneity on the riparian vegetation composition.

Table 4.7: Relationship between the morphological and the riparian vegetation species diversity.

Site	Number of morphological units	Number of species	Regression analysis output
VOLKERS RIVER			Constant -1.090 Standard error of Y estimation 1.433 R^2 0.654 Number of observations 16 X Coefficient 1.180
Va	5	3	
V1	3	5	
V2	4	5	
V3	5	3	
V4	5	5	
V5	8	7	
SKOENMAKERS RIVER			
S1	5	7	
S2	4	5	
S3	7	5	
S4	8	7	
S5	5	5	
S6	8	9	
S7	9	6	
S8	7	6	
S9	7	8	
S10	9	9	

An analysis of the results from plot sampling was performed to compensate for ‘between site variation’ of the riparian zone width. The following transformed species richness formula (Nilsson, *et al.*, 1997) was used to perform this analysis:

$$\text{Species Richness} = \frac{\text{Number of species}}{\log_{10} \text{area sampled}} \qquad (9)$$

The results of this analysis for the Skoenmakers River are presented by Figure 4.20. Comparison of this data with that of Table 4.7 suggests that if species richness is a function of the area sampled, then morphological diversity is also a function of area (i.e. channel width). High degrees of bank incision were observed at sites S2 and S5 (See cross-section profiles in Appendix 1) which resulted in a decrease in the area sampled. Species richness values calculated for these sites were lower than for the other sites and, therefore, indicate that a decrease in morphological diversity (due to incision) directly influences the riparian vegetation richness. The decrease in species richness at site S8 can possibly be explained by the high degree of disturbance at this site in the form of cultivation and riparian vegetation clearance right up to the river bank.

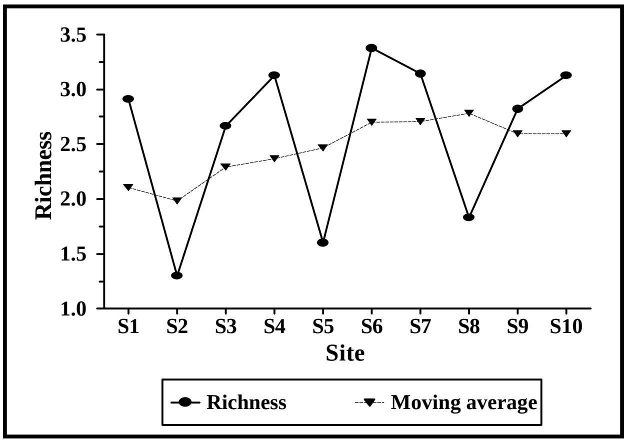

Figure 4.20: Transformed species richness for the Skoenmakers River.

Morphological diversity is influenced by the processes of incision, erosion and deposition. Due to the mutual relationship between the components of riparian vegetation and the geomorphology, the effect of changes to any of these processes will be reflected in the riparian vegetation.

It is evident from the results outlined in this section on the interrelationships between the vegetation and morphology of the river system that any change to any process or aspect of the geomorphology will clearly be reflected in the response of the vegetation. The IBT represents such a change for the Skoenmakers River. The response of the geomorphology to the IBT was discussed in Section 4.3 and it therefore appropriate at this stage to have a look at the results from the assessment of the influence of the IBT on the riparian vegetation of the regulated river.

4.5 IBT influence on riparian vegetation distribution and processes

4.5.1 Geomorphological changes

Any change in the geomorphology and morphological diversity of the regulated river due to the IBT will have a direct impact on the riparian vegetation due to the complex interrelationships between geomorphology and riparian vegetation (outlined in Section 4.4). Through this mutual relationship, the IBT will therefore have an indirect impact on the riparian vegetation and this should be kept in mind throughout the presentation of results on the assessment of the IBT influence on the vegetation.

Results from cross-sectional and plot sample vegetational surveys indicate that the impact of the IBT on the vegetation was most severe in the upper reaches of the Skoenmakers River. The dramatic changes in the geomorphology of this section of the river caused a decrease in the number of species recorded along the cross-section profile. The effect of the incised right-hand bank at site S5 (See Appendix 1 for the cross-sectional profile) is evident from the belt transect for the vegetation (Figure 4.21).

The mono-stand of trees on the right-hand bank top and the absence of other species clearly indicates the influence of the IBT on the vegetation structure for this site. The incision of the bank prevented establishment of other species due to a lack of the suitable sites.

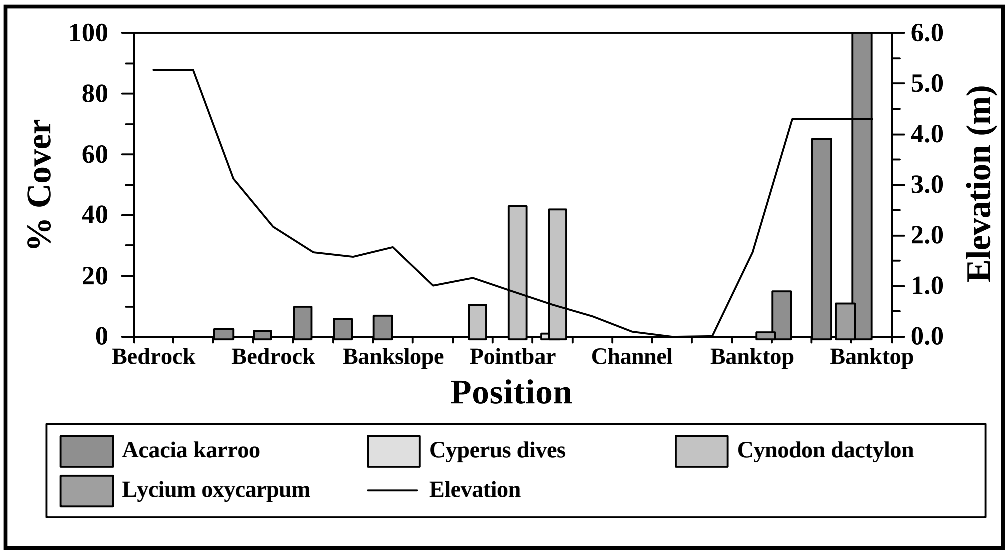

Figure 4.21: Belt transect for site S5 in the middle reaches of the Skoenmakers River (approximately 17 km below the IBT inlet).

A comparison of site S5 of the Skoenmakers River with V2 at the same distance downstream for the Volkers River further indicates the influence of the IBT on the riparian vegetation structure. The presence of grass species and juveniles of *Lycium oxycarpum* on the bank slope was recorded during plot sampling and is evident on the belt transect constructed from these findings (Figure 4.22). The lack of tree species, *Acacia karroo* and *Rhus lancea*, at this site is possibly due to the lack of sufficient water.

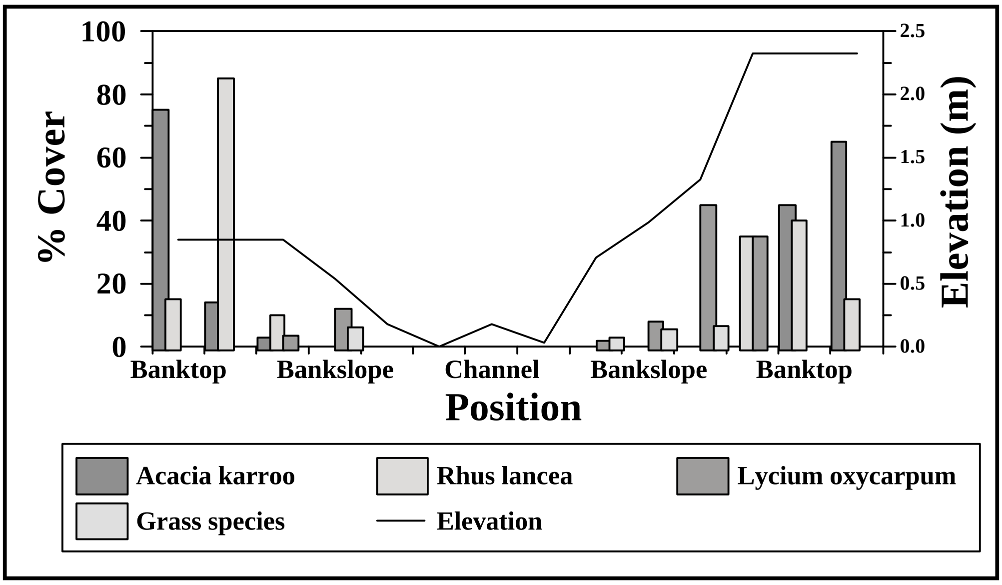

Figure 4.22: Belt transect for site V2 in the middle reaches of the Volkers River.

Morphological diversity was found to be an important factor influencing the spatial distribution of riparian vegetation (Section 4.4.2). The impact of the IBT on the heterogeneity of the physical habitat and therefore on the vegetation was evident for the Skoenmakers River. A comparison of the cross-sectional profile of site S6 on the regulated river with that of site V3 was presented in Figure 4.5. The results from plot sampling of the vegetation were superimposed on this profile to construct the belt transects for these two sites (Figure 4.23a and 4.23b). The higher species diversity due to the establishment of sedge species is evident at site S6 on the shelves which are absent from site V3.

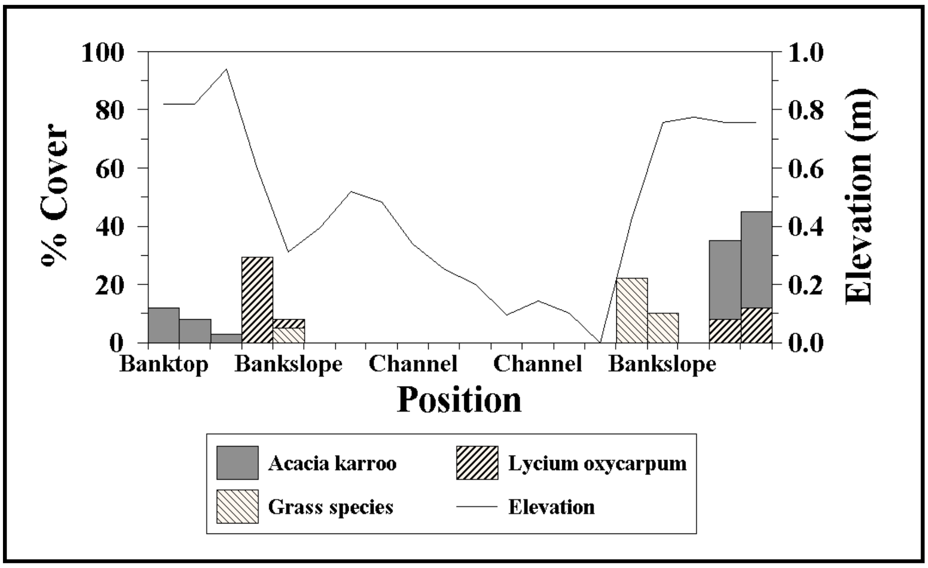

Figure 4.23a: Belt transect for site V3 in the middle reaches of the Volkers River.

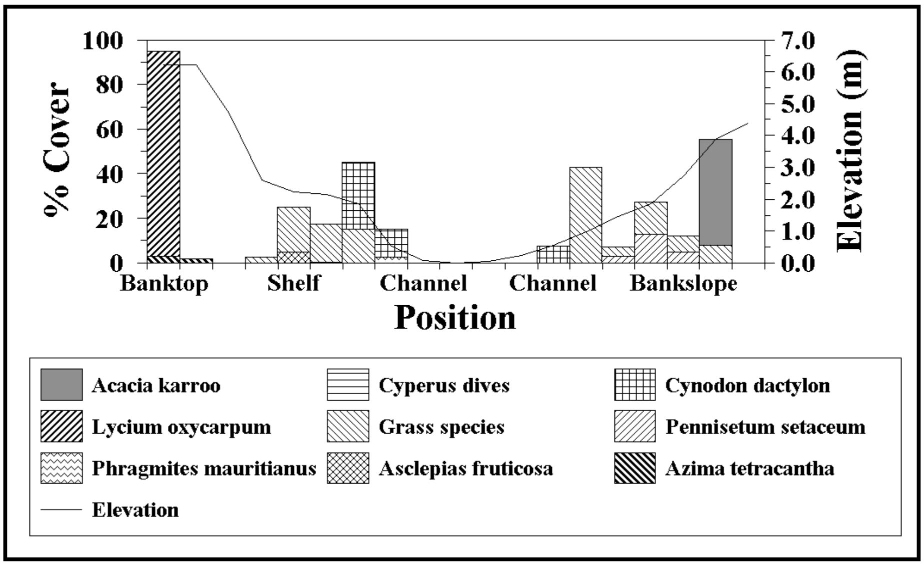

Figure 4.23b: Belt transect for site S6 in the middle reaches of the Skoenmakers River.

The presence or absence of certain species at certain sites can be linked to the sediment sorting processes. Results on the overall bank sediment sizes for the Volkers and Skoenmakers Rivers (Figure 4.13) indicated a higher percentage of finer sediment (fine sand, very fine sand and silt/clay) for the Skoenmakers River. Plates 4.3 and 4.4 present sites located in the middle reaches of the Volkers River and Skoenmakers River respectively. Sedge and grass species present at site S4 was associated with the higher percentage of finer sediment deposited on the shelf. Although the point bar deposition in Plate 4.3 created the ideal site for these vegetation types, the coarse sediment (lack of finer sediment) and lack of water prevented the establishment of these species.

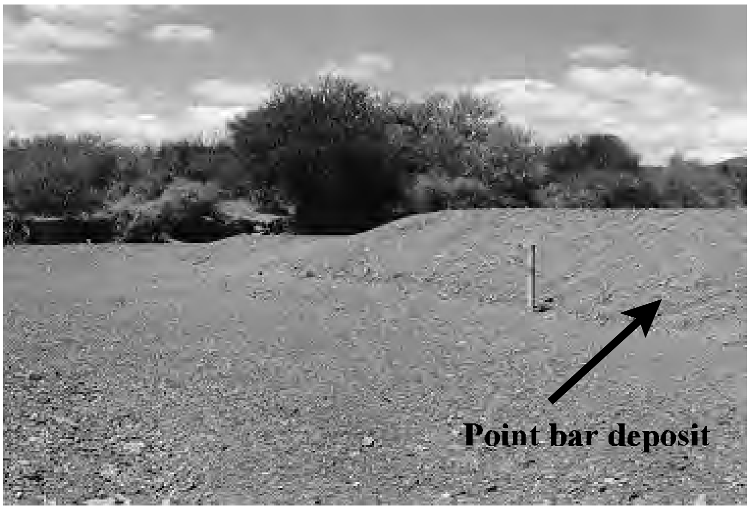

Plate 4.3: Point bar deposition upstream from site V3 in the middle reaches of the Volkers River.

Plate 4.4: Vegetated bar at site S4 in the middle reaches of the Skoenmakers River.

The indirect influence of the IBT (due to changes in the geomorphology) on the riparian vegetation distribution was evident from this section. It is not only the distribution however, of the vegetation that changed due to the IBT but the community composition of the Skoenmakers River's riparian vegetation as well.

4.5.2 Vegetation community composition

The first factor influencing the vegetation community composition is the number of species for a given site. The number of species was recorded for each plot at each site for both the regulated and non-regulated rivers and the average number of species was then calculated for each river section (upper, middle and lower reaches) as stipulated in Table 3.1. A comparison of this data showed a greater average number of species for the regulated river (Figure 4.24).

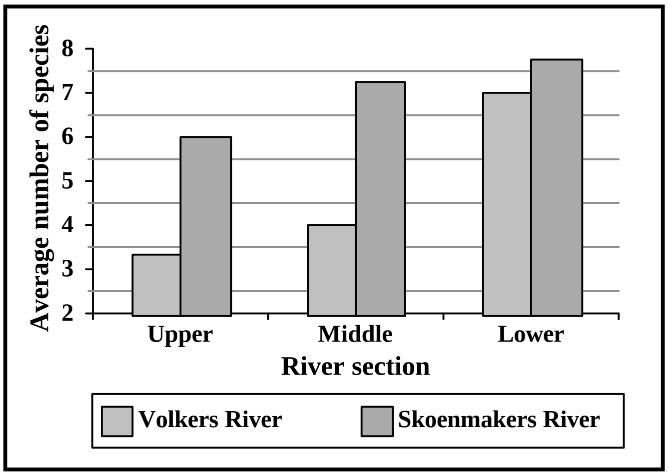

Figure 4.24: Average number of riparian vegetation species recorded for the Volkers and Skoenmakers Rivers.

The qualitative (descriptive) data recorded for the riparian vegetation (See Appendix 4) was used as an extension to the quantitative data gathered through plot sampling. This qualitative assessment involved observations on the extent, health, age, position, spacing, etc. These descriptive measures was used to point out any localised influences on the riparian zone which are not directly related to the IBT, eg. landuse changes, riparian vegetation clearance, etc.

Three important quantitative attributes of a vegetation community are the relative density, relative frequency and relative coverage, and any kind of disturbance would be reflected in these parameters. Importance values were calculated from these three parameters and then converted into importance percentages for each species at each site (Figures 4.25 and 4.26). These importance percentages give an overall estimate of the influence or importance of a plant species in the community.

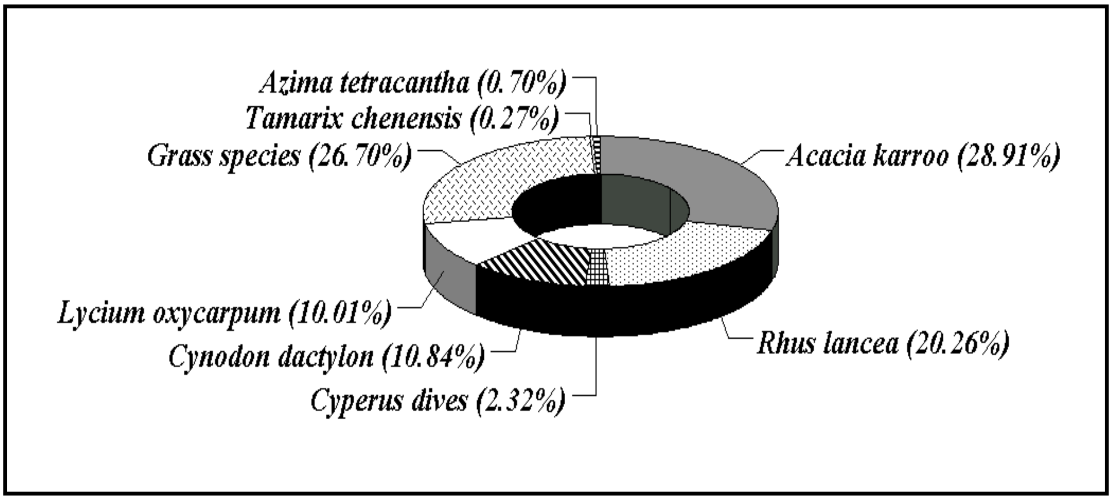

Figure 4.25: Importance percentages for species of the non-regulated Volkers River.

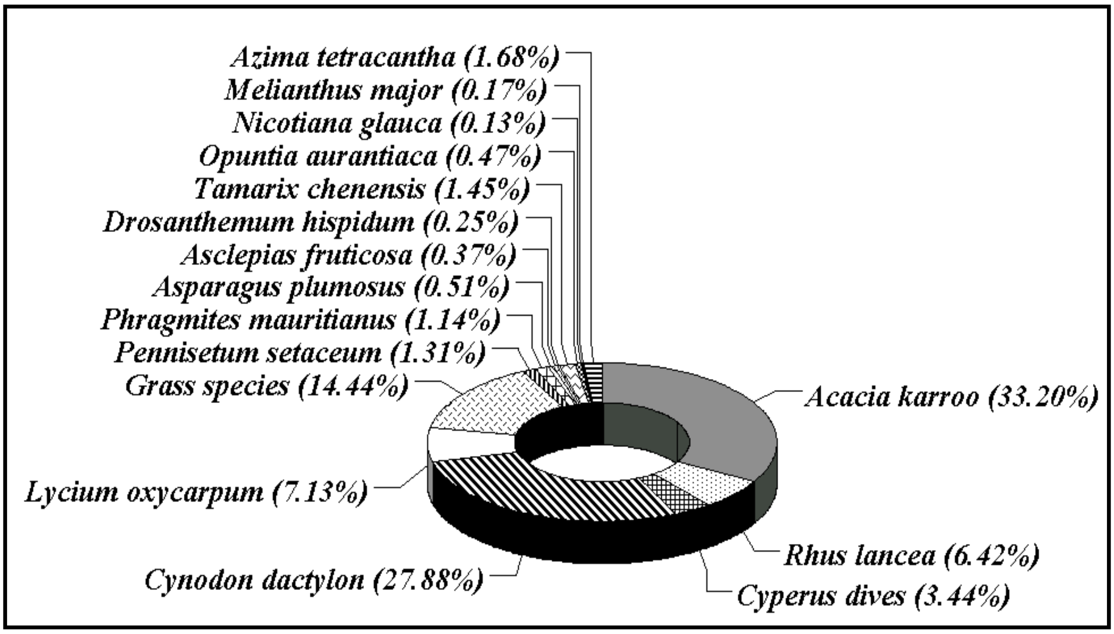

Figure 4.26: Importance percentages for species of the regulated Skoenmakers River.

A presentation of the importance percentages in terms of the different vegetation types, trees, grass and sedges (Figure 4.27) clearly shows a lower value for woody species along the regulated Skoenmakers River in comparison to the non-regulated river. On the other hand, significantly higher importance percentages were recorded for grass and sedge species along the regulated river when compared to the non-regulated Volkers River. Sedge species values more than doubled along the regulated river.

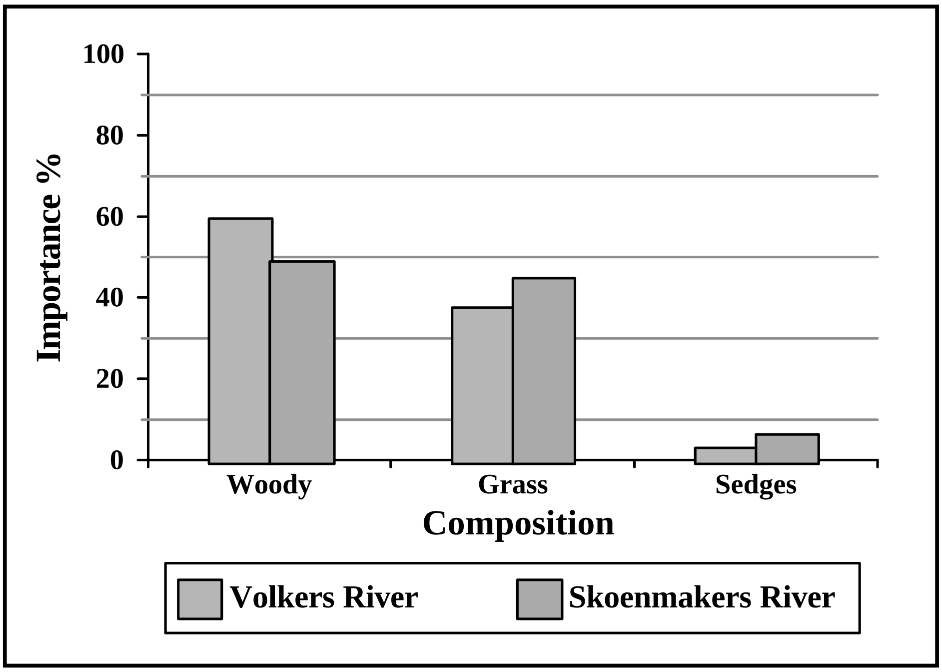

Figure 4.27: A comparison of the vegetation composition for the regulated and non-regulated rivers in terms of the importance percentages for each vegetation type.

It is important to keep in mind that sedge species normally establishes near the water's edge. Due to the lack of water in the ephemeral Volkers River (except for the lower-most site) no suitable sites for regeneration exist and therefore explain the absence of this vegetation type in the Volkers River. It is therefore evident that water availability can be seen as one of the primary factors limiting riparian vegetation community composition and spatial distribution in a semi-arid region such as the Karoo.

4.5.3 Water availability

The impact of the IBT on the water availability and changes in the hydrological regime of the Skoenmakers River was presented in Section 4.2. The post-IBT phase can be subdivided into the pre-1985 and post-1985 periods after the completion of De Mistkraal Dam. The effect of the additional water supplied to the recipient stream was evident from the comparison of the riparian zone width for selected sites along the regulated Skoenmakers River (Figure 4.28). The riparian zone width was derived from an aerial photograph analysis for the different phases (pre- and post 1985) of the Skoenmakers River's hydrological regime.

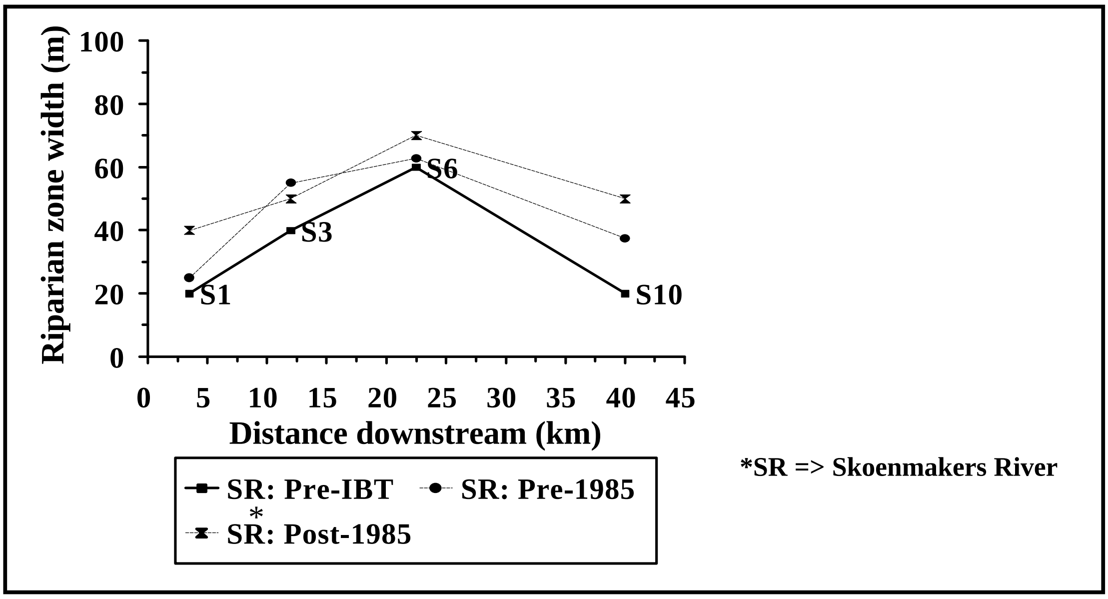

Figure 4.28: Influence of the IBT on the riparian zone along the Skoenmakers River.

Results from both the aerial photo analysis and fieldwork indicate a definite increase in the riparian zones for each section of the regulated Skoenmakers River at present when compared to the period before the completion of De Mistkraal Dam and the IBT. This is mainly due to the additional water available to the riparian species since the completion of the IBT in 1978 and De Mistkraal Dam in 1985.

It must be mentioned that the width of the riparian zones for the two rivers are greatly influenced by landuse activities and landuse changes close to the rivers. This is evident at site S3 for the post-1985 period and can be explained by the clearance of riparian vegetation at this site for cultivation. The overall increase in the riparian zone width for the other sites on the post-1985 curve indicates the impact of the increased flow caused by the completion of De Mistkraal Dam.

4.5.4 Landuse changes

Riparian vegetation clearance is evident from observations in the field for both the rivers. The clearance along the Skoenmakers River is most evident in the upper reaches as farmers started to cultivate the land close to the river. The additional water from the IBT had increased the capacity of the river for this purpose. A series of aerial photos (1960 to 1990) for the area along the Skoenmakers River was analysed and a comparison was made between the pre-IBT and post-IBT phases to indicate the influence of the IBT on the riparian zone (Figures 4.29 to 4.31).

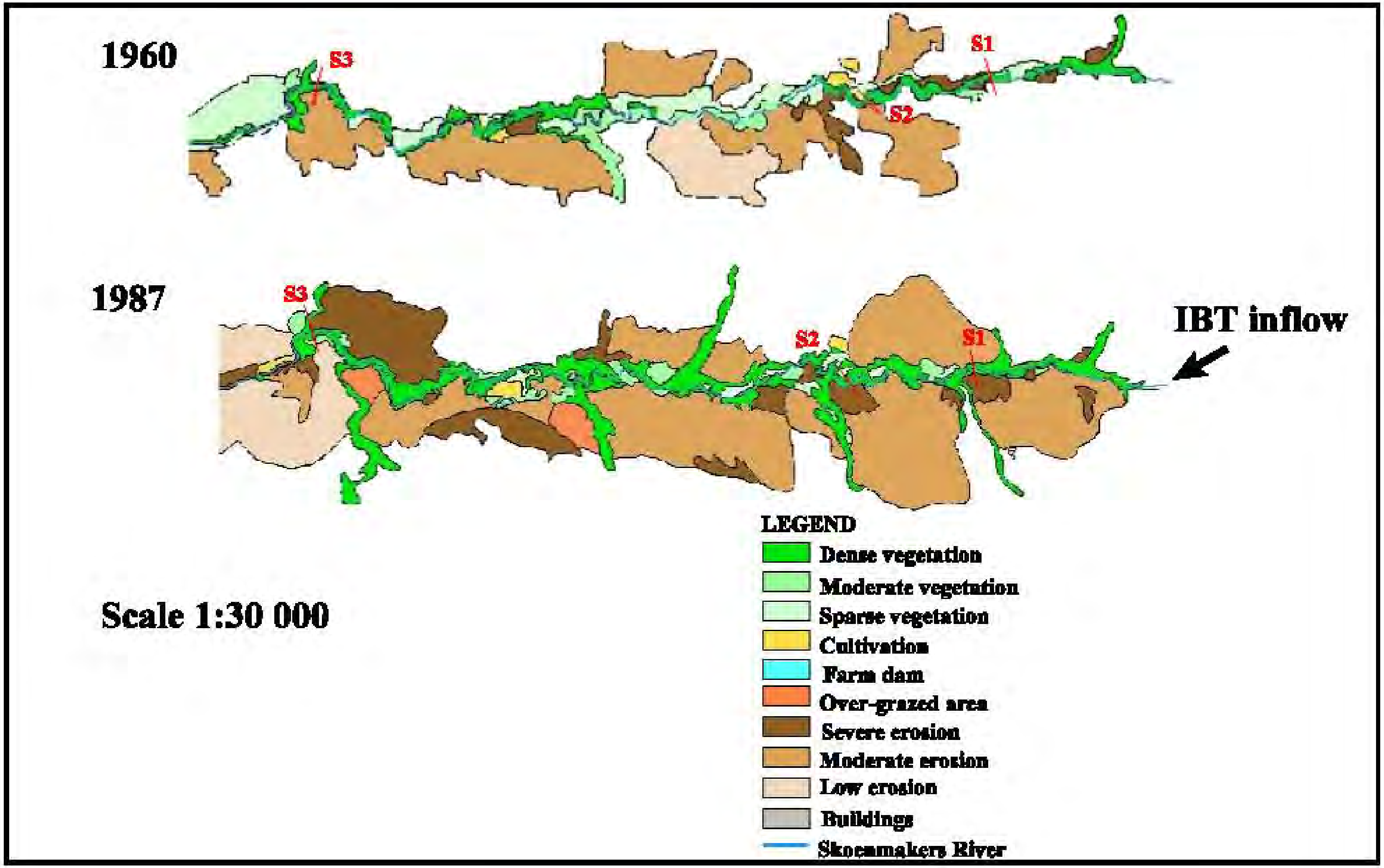

Figure 4.29: Landuse changes along the upper reaches of the Skoenmakers River for the pre-IBT (1960) and post-IBT (1987) phases.

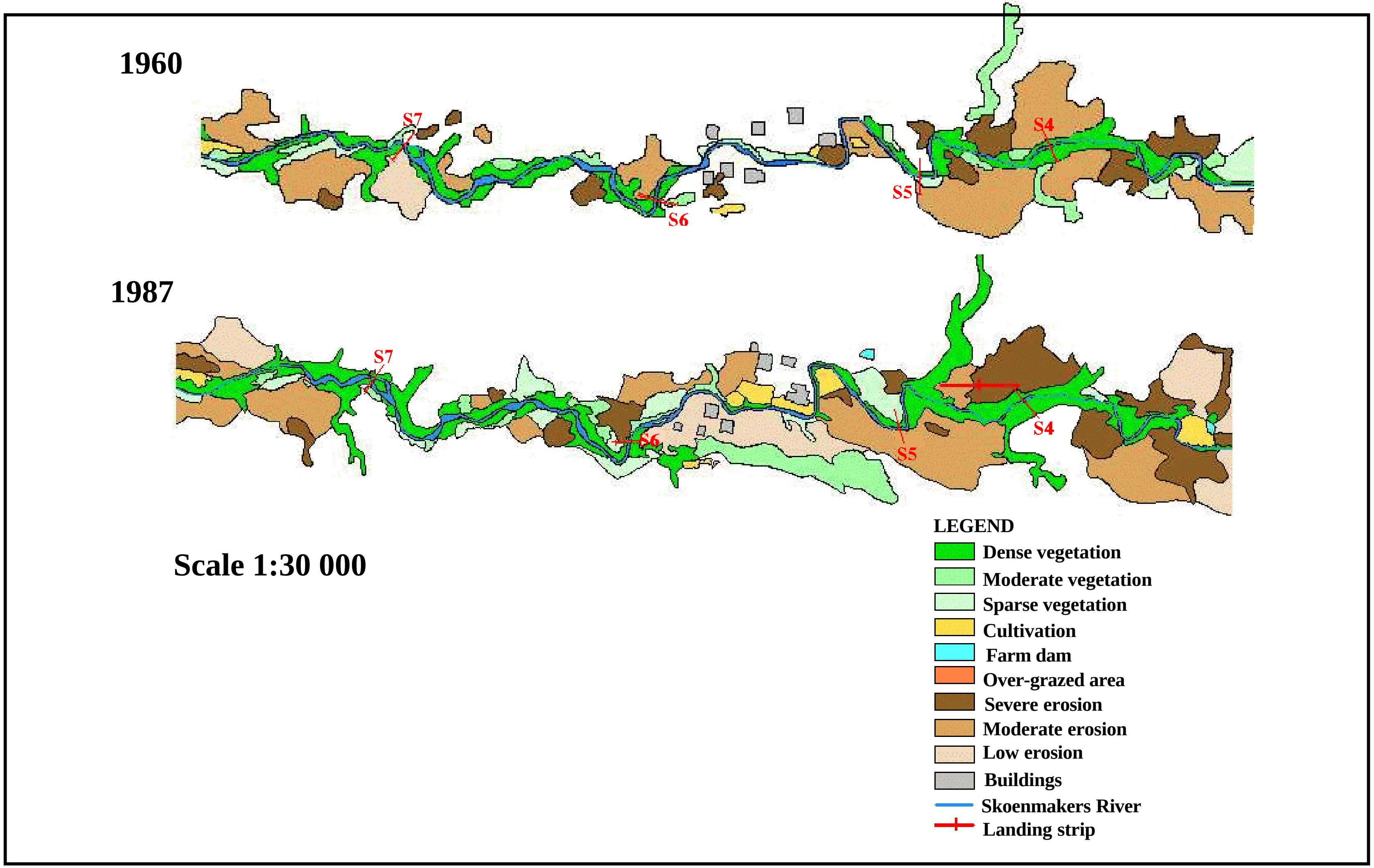

Figure 4.30: Landuse changes along the middle reaches of the Skoenmakers River for the pre-IBT (1960) and post-IBT (1987) phases.

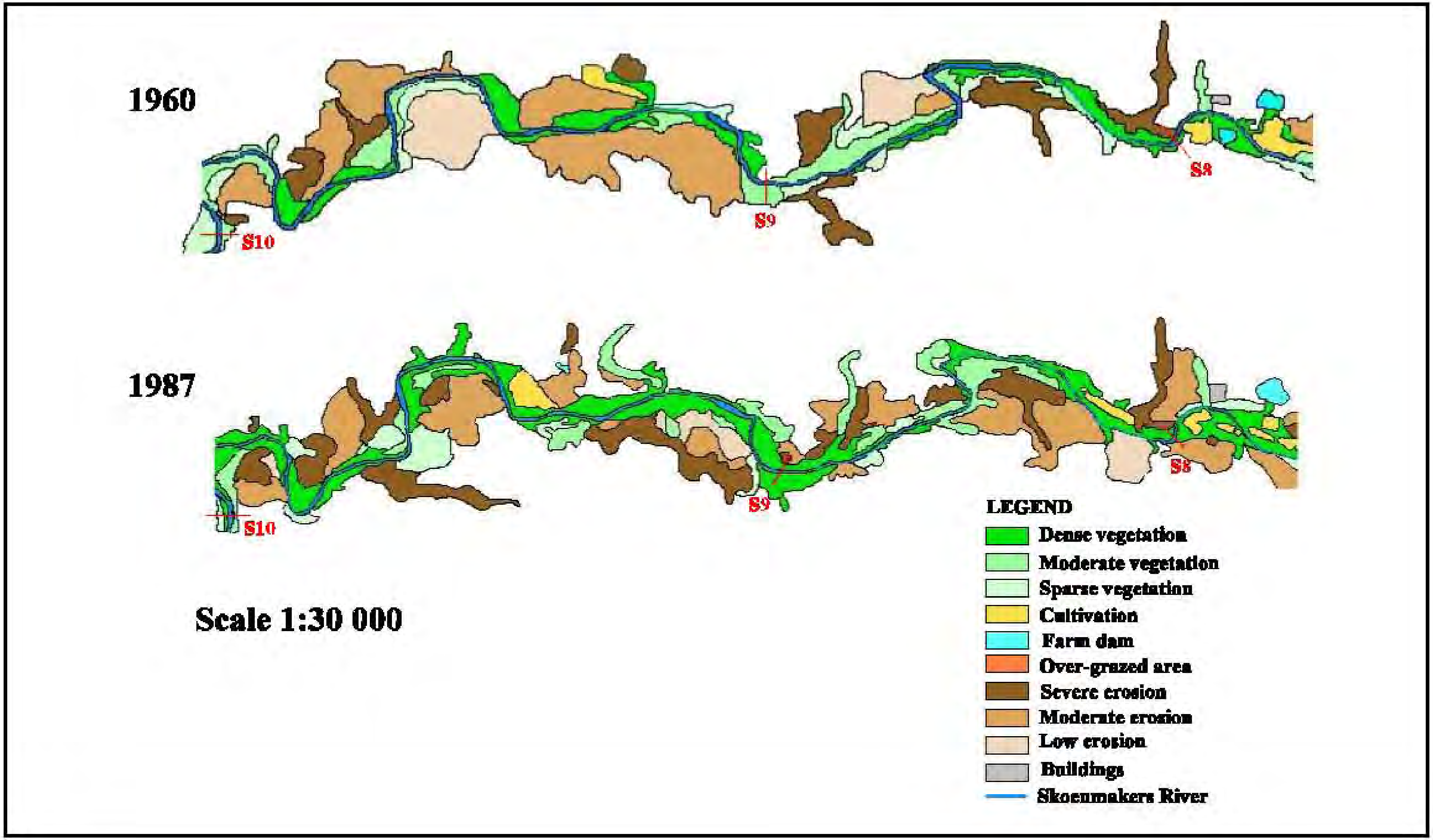

Figure 4.31: Landuse changes along the lower reaches of the Skoenmakers River for the pre-IBT (1960) and post-IBT (1987) phases.

Results of the aerial photo analysis indicate an overall increase in the density of the riparian vegetation for the upper, middle and lower reaches. This increase in density is most evident in the lower reaches of the Skoenmakers River and also along the tributaries of the river, where a consequent reduction in the degree of erosion can be seen (Figure 4.31).

Areas of cultivation showed an increase for all three river sections. A decrease in the riparian vegetation density was noticed for these cultivated areas due to riparian vegetation clearance. This is especially true for the upper reaches of the river where riparian vegetation (especially tree species, *Acacia karroo*) has been cleared to the extent that virtually no riparian zone is left.

4.6 Summary of results and conclusion

The results presented in this chapter showed the temporal changes in both riparian vegetation and geomorphology since the completion of the IBT in 1978. The spatial distribution of these changes in the two river components is related to the interactions between these two factors which had changed due to a change in the underlying processes.

The primary factor influencing all the other components was found to be the change in discharge for the Skoenmakers River from an ephemeral stream to a much bigger perennial river. The higher and seasonal flows caused by the IBT had a dramatic influence on the geomorphological diversity (morphological unit types) found in certain areas of the Skoenmakers River which, in turn, has led to changes in the riparian vegetation distribution and community composition.

It was evident from the results that a number of interrelationships exist between all the components of the river system. The complex multi-disciplinary nature of this kind of study was evident throughout the analysis of field and other data. This multi-disciplinary nature and the consequent underlying interrelationships of all the different river components should be kept in mind throughout the discussion on the results that follows.

Chapter 5: Discussion

5.1 Introduction

The changes to the hydrological regime of the regulated Skoenmakers River will be addressed in the first part of this chapter (Section 5.2). In the second part (Section 5.3) the response of the geomorphology of the Skoenmakers River to the Orange-Fish-Sundays River Interbasin Transfer Scheme will be discussed. The third part of the chapter (Section 5.4) deals with the response of the riparian vegetation to the changes brought about by the IBT. More specifically, the community composition, spatial distribution and the interrelationships with the river morphology will be addressed.

5.2 Hydrological changes

The flow regime of the regulated Skoenmakers River has changed from an ephemeral stream after 1978 to a perennial river with a maximum average daily flow of four cumecs in 1985. After the completion of De Mistkraal Dam in 1985, this regime changed yet again from a maximum average daily discharge of four cumecs to a maximum average daily flow of 22 cumecs (the full capacity of the Skoenmakers Canal). The change from an ephemeral to a perennial flow regime had a severe impact on the river system mainly due to the fact that the channels of semi-arid areas have longer recovery periods from extreme events and the effects of these events are therefore preserved for a long time.

The regime of semi-arid streams is characteristically unsteady and therefore relationships between process and form in ephemeral streams are less obvious than in humid areas and for perennial rivers. This is partly due to the fact that high-magnitude events have such a dominant influence on the geomorphological and hydrological components of the river system. The IBT changed this scenario dramatically as the flood dominated ephemeral stream was converted into a base flow dominated perennial river.

Flood water from the Little Fish has no effect on the Skoenmakers River system as these flood events are controlled at De Mistkraal Dam by closing off the inlet of water into the Skoenmakers Canal and allowing the flood water to flow over the dam wall into the Little Fish River. Simulated flow data indicated that natural floods occur in the Skoenmakers and Volkers River catchment approximately every 10 years (Water Research Commission, 1997).

Although floods in a semi-arid region are of low frequency, the high magnitude of these events controls the morphology of ephemeral streams. Due to the greater differences between high and low flows, the development of a close relationship between the channel form and particular discharge such as bankfull is prevented. The absence of a distinctive active channel was evident in the ephemeral Volkers River whilst, in comparison, cross sectional profiles constructed for the Skoenmakers River include very distinctive active channels.

Present flow data and releases from De Mistkraal Dam indicated a distinctive seasonal flow pattern for the Skoenmakers River (Figure 4.3) which was absent in the otherwise ephemeral stream. These discharge fluctuations are characterized by repetitions of a high flow and a low flow stage and are ecologically as well as geomorphological very important. During the high flow stage deformation of the river bed occurs and during the base flow stage riparian vegetation growth period and deposition of fine sediments are initiated (Tsujimoto and Kitamura, 1996).

Flow duration curves (Figure 4.2) constructed from the hydrological data (monthly flow data) indicate that before the completion of the dam very low flows as well as periods of no flow conditions occurred for approximately 20% of the time whilst these flow conditions are absent from the data for the post-1985 period. Periods with a flow of less than the average five cumecs have created favourable conditions for riparian vegetation species such as sedges to establish themselves as riparian vegetation needs a seasonal flow to maintain its structure, sediment sorting processes are contributed to and the deposition of finer sediments is introduced to the system. Return flows from irrigation above site V5 of the Volkers River has lead to the introduction of finer sediments and therefore sedge species became established.

IBTs can be seen as direct impacts on modern fluvial systems, with an immediate effect on the morphology and sediment load. Regulation of the former ephemeral Skoenmakers River can be seen as environmental manipulation due to the modification of the natural environment. Ecological requirements of river components such as the riparian vegetation were destroyed and/or modified beyond tolerance levels. These components and therefore riparian vegetation communities were changed and replaced by others.

It is important to keep the dynamic nature of fluvial systems in mind when assessing the influence of the IBT on the two components of geomorphology and riparian vegetation. It must also be recognised that the hydrological changes in the Skoenmakers River represent the primary underlying factor that influence the natural and physical environment.

5.3 Geomorphological changes

5.3.1 Long profile

The importance of the change in channel gradient downstream as a factor influencing the relationships between riparian vegetation distribution and river morphology was evident from the results. Both these two components react to any disturbance to the natural conditions of the river system (like an IBT) according to the distance downstream along the long profile. The general course of a long profile is as follows; steep gradient for the upper reaches, decreasing downstream until a very gentle gradient is achieved in lower reaches. This profile usually results in a concave curve with a division of rivers into upper, middle and lower reaches.

The long profiles for both rivers have been constructed by means of digitized Arc/Info covers (Figures 1.4 and 1.5). Both rivers (like most of the Eastern Cape rivers) deviate from simple models derived from northern temperate rivers. Long profiles do not follow the conventional concave form and tend to have a more convex profile due to rejuvenation in the recent geological past. The Skoenmakers River tends towards an almost rectilinear profile, with a significant knickpoint in the middle reaches of the river. This knickpoint is probably the result of a junction of the main stream with one of the bigger tributaries for the Skoenmakers River catchment (See Figure 1.3) and/or a change in the geology from the Beaufort Group (Koonap Formation) to the Ecca Group (Waterford Formation).

The long profile is divided into the upper, middle and lower reaches which can be linked to the degree of erosion and deposition. Although these two forces can be active along the whole river course, the subdivision into these three zones depends on the dominant force active:

- Zone 1: Production => Upper reaches;
- Zone 2: Transfer => Middle reaches; and
- Zone 3: Deposition => Lower reaches.

Field observations and sediment samples indicated that the division of the river sections in terms of the dominant morphogenic force was more defined and evident for the regulated Skoenmakers River when compared to the dry Volkers River. Severe erosion and incision occurred in the upper reaches of the Skoenmakers River, especially below the inlet of the IBT. Deposition of finer sediments in the middle and lower reaches of the regulated river occurred due to the increased sediment input into the river at the top of the system where the post-IBT baseflows are now much higher than the pre-IBT flood flows. The changes in sediment dynamics observed in the downstream direction of the Skoenmakers River clearly indicated that sorting processes which carry the finer particles downstream were contributed to in the Skoenmakers River. This is mainly due to the excessive sediment supply upstream.

The regulated Skoenmakers River follows the zonation of Schumm (1977) along the long profile. The upper reaches of the river is characterised by coarse material like boulders, large cobbles and gravel. Lower reaches, on the other hand, carry more sand and silt. Changes in the sediment sorting processes of the non-regulated Volkers River is much less clear-cut and the analysis of sediment samples indicated similar sediment sizes for most of the sites along the long profile. These changes to the long profile of the Skoenmakers River due to the IBT had a direct influence on the geometry of the river channel and cross-sectional surveys of the two rivers confirmed this statement.

5.3.2 Cross-section

Results from cross-sectional surveys indicated that the two cross-section components, depth and width, adjusted to altered conditions within the regulated Skoenmakers River. The degree and rate of these adjustments was found to be strongly dependent upon the quantity of water moving through the cross-section as this, in turn, affects the processes of erosion and deposition. These two processes play an important role in local bank conditions and the lateral stability of banks depend to a large degree on the strength of the bank material.

An analysis of the downstream changes in geometry of selected sites showed a steady decrease in the depth downstream for the regulated river, whilst an increase in depth from the upper to middle reaches was measured for the non-regulated Volkers River. An increase of the bank top width in a downstream direction was evident for both rivers (Figure 4.8). The severe impact of the IBT on the geometry of the regulated river below the IBT inlet was evident from the high value of almost 30m recorded for the width of the Skoenmakers River in comparison to the five metres recorded at Site Va along the Volkers River. This indicated severe erosion of the banks at Site S1.

Channel incision at Site S1 of the regulated Skoenmakers River was evident from the analysis of the cross-sectional data. A depth of approximately eight metres was recorded at Site S1 in comparison to the 0.5m recorded for Site Va at the same distance downstream along the non-regulated Volkers River. Results of the cross-sectional surveys also indicated that deposition had increased in the lower part of the regulated river's system as a lower depth value was recorded at Site S10 of the Skoenmakers River in comparison to Site V5 of the non-regulated river. Aggradation of the river bed was prominent in this section of the regulated river.

A comparison of cross-section profiles for the regulated and non-regulated rivers suggested that the IBT had a more serious effect on the upper reaches of the Skoenmakers River. Severe erosion and incision occurred in these areas due to the IBT. This change in cross-sectional profile due to the IBT was most severe below the inlet of the IBT into the Skoenmakers River. A comparison of two sites at equal distances downstream for the two rivers indicated that the average macro-channel width of the regulated river's channel showed an increase of up to 300% due to the severe bank erosion. Incision of the channel bed led to an increased depth up to the point that the bedrock had been exposed. Incision and undercutting of the riverbanks in this area is quite severe and therefore enhances bank collapse and sediment input into the river. Observations in the field confirmed the instability of the bank in this area which are contributed to by the weight of the trees (*Acacia karroo*) at the top of the banks.

The impact of the IBT was still serious but much less severe approximately 15 km downstream from the inlet. The degree of erosion and incision is lower for this area and therefore the difference in the width and depth of the channel between these two sites is not as prominent as for sites S1 below the IBT inlet into the Skoenmakers River and Va at the top of the Volkers River system. One of the most interesting characteristics of open systems such as streams is their capacity for self-regulation. Feedback mechanisms act to stabilize the system so that some degree of equilibrium can be established. The similarity of the cross-sectional profiles for two sites in the lower reaches of the Skoenmakers and Volkers Rivers is evident from Figure 4.7. This indicates that the lower reaches of the regulated river were able to ‘absorb’ the impact of the IBT much better than the upper reaches and can be explained by the fact that this part of the river system is naturally formed by large flood discharges. It was found, however, that although the macro-channel of the regulated river can accommodate the increased baseflow in the lower reaches, the form of the channel in this part of the system was still altered by increased aggradation.

The impact of the IBT on the geometry in the middle reaches of the regulated river (approximately 25 km downstream) is less severe in comparison to the upper reaches as the banks become more stable. The cross-sectional profiles for sites in the middle reaches of the Skoenmakers River was found to be more diverse in terms of the type of morphological units present when compared to the non-regulated Volkers River. This can be seen as a positive influence of the IBT on the ecological components of the river system, eg. riparian vegetation, invertebrates, etc. as a more diverse morphology means more diversity in species. The question now arises surrounding the concept of ‘diversity’. The natural environment of species adapted to the semi-arid conditions along the ephemeral stream has been altered to accommodate more (perennial) species which has led to a change in the communities along the river. Although this change meant a more diverse environment on a local scale, it must be kept in mind that the unique physical and hydrological and biological characteristics of the semi-arid region were compromised through this action and therefore diversity on a regional scale was lost. The semi-arid conditions (environment) were replaced with more humid conditions.

Morphological diversity or heterogeneity was found to be a very important factor influencing the riparian vegetation distribution patterns and *vice versa*. This diversity is related to the number of morphological units at a specific site (Table 4.5) and from the results of the vegetational and geomorphological surveys it was evident that an important interrelationship exists between the number of morphological units and riparian vegetation species.

An assessment of the relationship between the number of morphological units and number of species was done by means of regression analysis for the Skoenmakers and Volkers Rivers (Table 4.7). The R squared values for the two rivers clearly indicate the positive correlation between the number of morphological units and the number of species at each site and therefore the influence of the morphological heterogeneity on the riparian vegetation composition. Research by Nilsson *et al.* (1991) confirm that a positive correlation exists between number of sediments and species richness. In other words, an increased morphological diversity (heterogeneity) increases species diversity.

It is important to remember that all fluvial systems are dynamic and have the ability to change form in response to forces active upon them. In the short term the fluvial system attains stability or equilibrium marked by balance between erosion and deposition. It is evident therefore that erosion and deposition processes will have a direct influence on the morphological diversity of the cross-sectional profile as these processes influence the condition of the banks.

5.3.3 IBT influence on the banks and channel of the regulated river

Bank erosion is the result of moving grains on the bank region subjected to transverse gravity pull due to the lateral inclination of the bank. The degree of erosion (or deposition) depends on the balance between the erosive force of flow and erodibility of the sediment and these are both affected by riparian vegetation. This erosion process depends on the geotechnical properties of bank material, for example the presence or absence of cohesion. Banks are generally divided into cohesive and non-cohesive based on their boundary composition.

Cohesive banks are usually eroded by the detachment and entrainment of aggregates or crumbs of sediment that are much less susceptible to flow erosion than non-cohesive banks. In non-cohesive banks, material is usually detached and entrained grain by grain. The banks of the two rivers in the study area can be classified as stratified banks. These are alluvial banks which usually consist of layers of non-cohesive and cohesive materials. Generally, non-cohesive layers erode more quickly than cohesive ones and this lead undercutting where non-cohesive material underlies cohesive material, or to the generation of shelves where cohesive material underlies non-cohesive material.

Active undercutting was evident in the upper reaches of the Skoenmakers River where non-cohesive material was eroded by the force of the water, transported downstream and deposited lower down the system. Although erosion was also evident in the upper reaches of the Volkers River, little or no undercutting was observed. Undercutting led to bank collapse and attributed to sediment input into the channel and the middle and bottom of the banks.

A comparison was made of the average sediment type for the banks of all the sites according to the location along the length of the rivers, i.e. for the upper, middle and lower reaches of the Volkers and Skoenmakers Rivers. The sediment samples taken for the Skoenmakers River show overall significantly higher percentages of finer sediment when compared to the Volkers River. This can be explained by the higher flows (perennial conditions) in the former ephemeral Skoenmakers River which contributed to the supply of finer sediments at the top of the system and therefore, the deposition of this finer sediment along the length of the river. The middle reaches of the two rivers shows similar sediment classes, tending towards sandy banks, and can be explained by the fact that the middle reaches of a river can be seen as the transitional zone of sediment (according to Schumm, 1977).

The distribution of the average sediment size for each river (Figure 4.14) indicated overall finer sediment for the Skoenmakers River. The highest percentage values recorded for the sediment of the Skoenmakers River were for the sediment classes between medium sand and very fine sand. In comparison, the highest values for the Volkers River were between fine gravel and coarse sand. The percentage silt in the Skoenmakers River showed an increase of approximately 100% when compared to the Volkers River. This is due to the contribution of the IBT to the sediment sorting processes and the introduction of finer sediment to a former ephemeral system through enhanced erosion caused by the additional water.

The impact of the IBT in the middle and lower reaches of the Skoenmakers River is less severe in terms of the degree of erosion and higher degrees of bank accretion were observed for these areas. Point bars were formed in the Skoenmakers River but were absent in similar areas of the Volkers River. The most prominent difference in bank conditions for the Skoenmakers and Volkers Rivers can be seen in the formation of shelves. A qualitative assessment of the bank conditions for six representative sites along the two rivers showed the absence of shelves in the middle reaches of the Volkers River (Site V3). In comparison, well-developed shelves were formed at site S6 on the Skoenmakers River.

Channel shelves are important riparian and ecological features with horizontal to gentle sloping surfaces that normally extends the short distance between the break in the relative steep bank slope and lower limit of persistent woody vegetation that marks the channel-bed edge. These features were found to be best developed along relative steep-gradient reaches like reach 3 of the Skoenmakers River below the knickpoint in the long profile (See Figure 1.5).

The formation of shelves in the middle and lower reaches of the Skoenmakers River might be an indication of the so-called *quasi equilibrium* in *Stage VI* of the six-stage model by Simon and Hupp (1990). Field observations and on-site comparison of the sediment deposits of the banks indicated that these morphological units might be depositional features. This assumption was confirmed by on-site comparison of the sediment supplied to the channel at the top of the system and which is now being transported by the river and deposited downstream. The similarity between the sediment deposits of the shelves and that of the sediment upstream is greater than that of the bank deposits. It can therefore be concluded that these features are depositional rather than the product of bank collapse, although bank slumping might have contributed to the formation of these morphological units.

The influence of the IBT on the bank (and the channel) condition of the Skoenmakers River can be conceptualised following the *Six-stage model of channel evolution* after Simon and Hupp (1990). It can be assumed that *Stage I* of Simon and Hupp's model is equivalent to the Skoenmakers River in the *pre-IBT phase* as there was no modification to the channel. *Stages II and III* of the model can be compared to the initial response of the Skoenmakers River's channel form and the riparian vegetation to the IBT as *erosion* of the channel banks was *initiated* below the inlet due to the force of the additional water (Figure 5.1).

Severe erosion, and therefore widening, of the Skoenmakers River's channel in the upper reaches was evident from the results of cross-sectional surveys and therefore the *present state of the river channel in this section* can be compared to *Stage IV* of the six-stage model. Bank collapse was evident in these areas. The weight of the *Acacia karroo* trees on the top of the banks contributed to the bank collapse, especially in areas of undercutting of the banks.

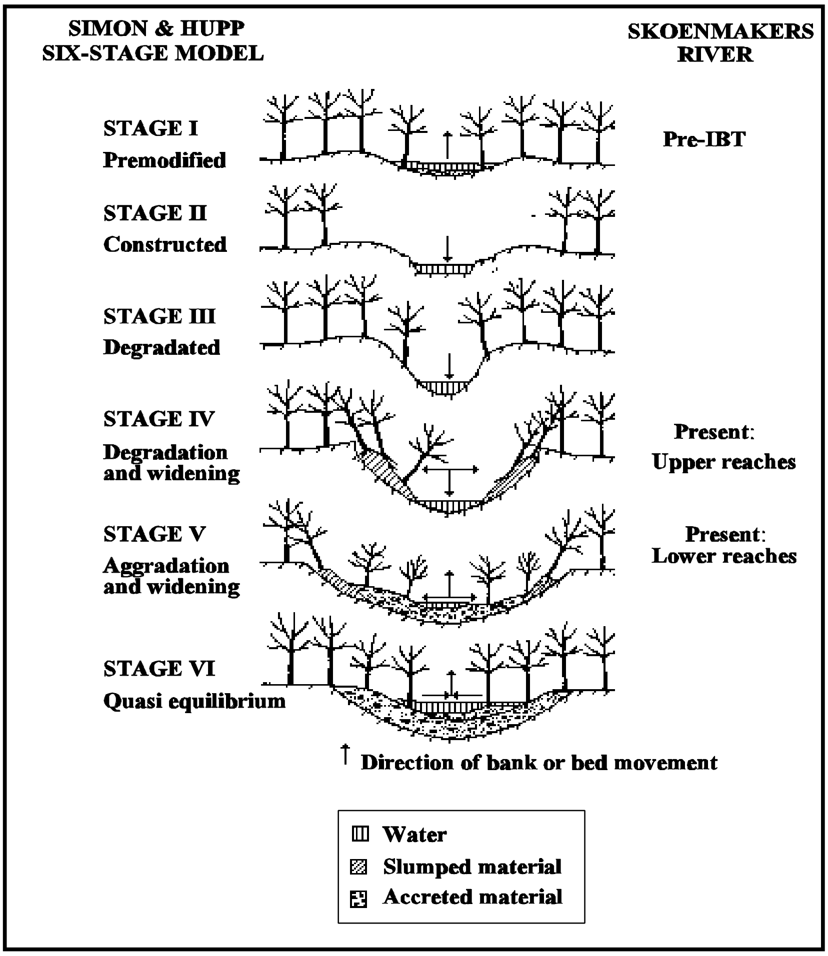

Figure 5.1: Conceptualisation of the impact of the IBT on the Skoenmakers River's banks according to the Six-stage model of Simon and Hupp (1990).

At present, the lower reaches of the Skoenmakers River can probably be compared to *Stage V* of the model as high degrees of bed *aggradation* were observed in these areas. Some localised erosion of the banks is evident in this section of the regulated river and it can therefore be assumed that the channel is also *widening*. It is evident from this model that the response of the channel banks goes hand-in-hand with the response of the channel to an outside influence.

Alluvial rivers like the Skoenmakers and Volkers Rivers form channels through the interaction of flowing water and a mobile boundary consisting of the sediment being transported by the river, eg. gravel, sand, silt, etc. These factors contribute to the fact that alluvial rivers are not static and continually change their position. Different channel forms develop as result of interaction between stream energy, sediment load and perimeter material.

Channel modification due to the IBT also follows the Six-stage model by Simon and Hupp (1990) as discussed in Section 5.3.3 and Figure 5.1. *Stage IV* can be compared to the state of the river channel in the upper reaches of the Skoenmakers River where a high degree of d*egradation* was observed. Lower down the system aggradation increased and can therefore be compared to *Stage V* of the model.

An important concept in channel form is the lateral shift of a channel which can occur naturally or can be enhanced by an outside influence. A comparison of a set of *pre-IBT* (1960) and *pos-IBT* (1990) aerial photographs for the upper reaches of the Skoenmakers River (Figure 4.15) clearly indicated a lateral shift in the planform of the river. Calculations of the Sinuosity Index (SI) indicated a change in the sinuosity of between 0.2 and 0.04 for the upper reaches of the Skoenmakers River for the post-IBT phase. The impact of IBT on the sinuosity is more serious higher up the Skoenmakers River system as a much greater difference between the SI values (0.2) was recorded for the pre- and post-IBT phases than lower down the system. The change of 1.9 to 1.7 indicates a lower degree of meandering for that part of the Skoenmakers River system in the post-IBT phase.

Probably the most prominent change in the channel of the Skoenmakers River is the incision of the channel bed in the upper reaches to such a degree that the bedrock has been exposed. Other observations on changes to the channel due to the IBT include:

- An initially wider active channel zone (increased width);
- armouring of the bed due to the removal of finer sediment;
- more bed material further downstream due to sedimentation; and
- decreased lateral stability of the channel.

Lower down the Skoenmakers River, in the middle and lower reaches, the impact of the IBT on the channel condition was much less severe. The only difference could be seen in the introduction of finer sediment into the Skoenmakers River's system which led to the formation of morphological units such as mid-channel bars which are absent or less prominent in the Volkers River's middle reaches.

It was evident throughout this study that changes to the geomorphology of a river will have a significant impact on the riparian vegetation due to the mutual relationship between these two river components. The impact of the IBT on the riparian vegetation of the regulated river will therefore be either direct due to the changes to the hydrological regime (Section 5.2) or indirect via the changes in the geomorphology discussed in this section of the chapter (Sections 5.3.1 to 5.3.3).

5.4 Changes to the riparian vegetation

5.4.1 Vegetation community composition

The influence of the IBT on the Skoenmakers River in terms of the composition of the riparian vegetation is most evident in the results from the plot samples. A comparison of vegetation data for the regulated and non-regulated rivers showed a greater average number of species for the regulated river. This increase in the number of species is mainly due to the introduction of sedge species to the former ephemeral system as a result of the available water and was evident from calculations of the importance percentages of the individual species.

The importance percentage of a species gives an overall estimate of the influence or importance of a plant species in the community. Each species' importance percentage was calculated from the relative density, relative frequency and relative coverage and any kind of disturbance would be reflected in these parameters.

A presentation of the importance percentages in terms of the different vegetation types, trees, grass and sedges (Figure 4.27) clearly shows a lower value for woody species along the regulated Skoenmakers River in comparison to the non-regulated river. On the other hand, significantly higher importance percentages were recorded for grass and sedge species along the regulated river when compared to the non-regulated Volkers River. Sedge species values more than doubled along the regulated river. Results indicated less dominance in the regulated system as the importance values for tree species shows a decrease whilst that of the other species like grass and sedges showed higher values when compared to the non-regulated Volkers River.

It is important to keep in mind that sedge species normally establish near the water's edge. Due to the lack of water in the ephemeral Volkers River, except for the lowermost site where return flows from irrigation is available in the channel, no suitable sites for regeneration exist and therefore explain the absence of this vegetation type in the Volkers River. It is therefore evident that water availability can be seen as one of the primary factors limiting riparian vegetation community composition and spatial distribution in a semi-arid region such as the Karoo.

Phragmites mauritianus was introduced to the Skoenmakers River system at localised areas of disturbance where the deposition of sediment was contributed to. The constant supply of water to the system would be favourable for the establishment of this species as *P. mauritianus* is a perennial species and needs a constant water supply for survival. Sediment moisture was found to be the limiting factor for establishment and persistence (spatial distribution) of not only *P. mauritianus*, but all the riparian species. The spatial distribution of these species will therefore depend on a number of other factors linked to sediment moisture and the water level fluctuations, eg. sediment type, elevation above the water level, etc.

5.4.2 Spatial distribution

The spatial distribution of riparian vegetation is one of the most important interrelationships between the morphology and vegetation of a river system. This interrelationship strongly depends on the site preferences of the different species and the availability of specific sites. Site availability is strongly dependent on sediment sorting processes such as deposition and erosion and therefore the type of sediment present. The influence of the IBT on the site availability to the species is probably the most prominent factor influencing the spatial distribution of riparian vegetation along the Skoenmakers River.

The average number of species for the three river sections (upper, middle and lower reaches) was calculated (Figure 4.16) and showed a steady increase in the number of species along the length of both the regulated and non-regulated rivers. This spatial distribution results in the longitudinal vegetation gradient (Van Coller, 1992). The number of species showed overall higher values for the regulated river which can be explained in terms of the additional water and sites (consisting of different sediment types) made available by the IBT.

The downstream zonation was found to be greatly affected by the specific characteristics of the sediment present. The other controlling factors was found to include the following:

- the quantity of water (water level);
- the channel width;
- the channel depth; and
- the distance downstream.

Rates and types of sediment deposition have been shown to be important factors affecting riparian vegetation distribution patterns. Most sediments available for seedling establishment in the lower reaches are alluvial, thus hydraulic sorting of sediment sizes and the rate of bed, bar or bank accretion are important geomorphological processes influencing vegetation distribution. Many riparian species are therefore restricted to a narrow range of sediment types that allow successful seed germination.

Patterns of riparian species distribution are strongly associated with the geomorphological stage of adjustment. Deep-rooted plants can withstand erosive forces and therefore it is more likely to find these species in the upper reaches where erosion represents the dominant morphogenic force. In comparison, plants usually associated with deposition are represented by shallow-rooted species that will grow with the accumulating sediment. This explains the findings of the increased cover percentages for riparian species such as sedges in the lower reaches and other depositional areas such as channel bars, and the dominance of tree species along the upper reaches (coarser material).

This site preference of species of different vegetation types or communities explains the spatial distribution of the riparian vegetation. Plant communities are defined as a collection of plants showing a definite association with each other (Kent and Coker, 1992). This association implies that certain species are found to grow more frequently in certain locations and environments than would be expected by chance.

The IBT resulted in changes in the sediment sorting processes and therefore also resulted in changes in the vegetation distribution along the longitudinal vegetation gradient. Sedge and grass species were introduced at a much greater distance downstream for the Volkers River, with sedges (*Cyperus dives*) only present in plot samples from the lower most site. Deposition of finer sediments in the middle and lower reaches had increased for the Skoenmakers River when compared to the Volkers River (Figures 4.12 and 4.13) and resulted in grass and sedge species establishment whilst the coarse sediment of the Volkers River channel prevented the recruitment of seedlings in these areas.

Tree species (*Acacia karroo* and *Rhus lancea*) tend to be the dominant vegetation type farther away from the active channel. Closer to the active channel, on the bank slope and shelves, grass species becomes established along with juveniles of the woody species. The bottom of the banks, the water's edge and channel bars (mid- and point bars) are dominated by sedge species (eg. *Cyprus dives*), reeds (*Phragmites mauritianus*) and grass species (*Cynodon dactylon).* This spatial distribution of vegetation types along the cross-sectional profile was found to be related to the elevation above the channel bed (Figure 4.17) and was found to be closely related to the horizontal vegetation gradient identified by Van Coller (1992).

It is important to realise that a mutual relationship exists between vegetation and geomorphology and therefore the riparian vegetation distribution influences the morphology of the river as well. Results from sediment sample analyses indicated that vegetation enhances the deposition of finer sediment as higher percentages of the finer sediment classes (fine sand, very fine sand and silt) was recorded for vegetated mid-channel bars (Figure 4.19). It was evident that the establishment of riparian vegetation on these features enhanced stability and helps absorb the changes to the geomorphology due to the IBT.

5.4.3 Changes in the riparian vegetation due to changes in morphological structure and diversity

Any change in the geomorphology and morphological diversity of the regulated river due to the IBT had a direct impact on the riparian vegetation due to the complex interrelationships between geomorphology and riparian vegetation. Through this mutual relationship, the IBT will therefore have an indirect impact on the riparian vegetation. It was evident, therefore, that cycles of build-up and erosion of sediment occurred as vegetation grew and then died.

Results from cross-sectional and plot sample vegetational surveys indicate that the impact of the

IBT on the vegetation was most severe in the upper reaches of the Skoenmakers River. The dramatic changes in the geomorphology of this section of the river caused a decrease in the number of species recorded along the cross-section profile. Mono-stands of trees were recorded in areas of bank incision. The effect of bank incision prevented other species from establishing due to a lack of suitable sites. A comparison of areas of incision along the Skoenmakers River with areas at the same distance downstream for the Volkers River indicated the influence of the IBT on the riparian vegetation structure. In some areas the presence of grass species and juveniles of *Lycium oxycarpum* on the bank slope was recorded for the Volkers River (Figure 4.22) but were absent from similar areas along the Skoenmakers River where incision of the banks occurred. The absence of the two tree species, *Acacia karroo* and *Rhus lancea,* in these areas can be explained by the lack of sufficient water in the ephemeral Volkers River system.

As mentioned in Section 5.3.2 morphological diversity was found to be an important factor influencing the spatial distribution of riparian vegetation. This diversity is related to the number of morphological units at a specific site (Table 4.5), and from the results of the vegetational and geomorphological surveys, it was evident that an important interrelationship exists between the number of morphological units and riparian vegetation species. A regression analysis was done for the relationship between the number of morphological units and number of species for all of the sites along the Skoenmakers and Volkers Rivers (Table 4.6). The R squared values for the two rivers indicated that a positive correlation exists between the number of morphological units and the number of species at each site.

An analysis of the results from plot sampling was performed to compensate for 'between site variation' of the riparian zone width. The transformed species richness formula (Nilsson, *et al.*, 1997) was used in performing this analysis and it was evident that the decrease in morphological diversity, due to erosion and incision, directly influenced the riparian vegetation richness as species richness values were the lowest for sites where these processes were observed.

A comparison of the belt transects for sites along the middle reaches of the two rivers (Figures

4.23a and 4.23b) indicated higher species diversity for the regulated river due to the establishment of sedge species. The shelves formed along the middle reaches of the regulated river were absent from similar sites for the middle reaches of the Volkers River. The presence or absence of these species on these features can be linked to the sediment present as sedge species prefer the finer sediment found on shelves.

The process of plant succession along rivers is usually initiated on new alluvium deposited during the flood-stages. New space for the deposited sediment has to come from the destruction of older sections of the bank or floodplain. This constant replacement of older sediment-vegetation complexes by new successional units results in specific structure of riparian vegetation (Gill, 1973). The removal of existing vegetation and/or sediment, as well as deposition of sediment and vegetation on existing sites, is determined by the disturbance of flooding which is the basic underlying factor to the change in the geomorphology and riparian vegetation of the former ephemeral Skoenmakers River.

The steady change in grass and sedge species and therefore vegetation community composition can be linked to the effects of the raised water level in the Skoenmakers River. The dramatic change in the flow regime and discharge of this system had an influence on the sediment sorting processes and size which was sufficient to alter the habitat for plants. The worst possible flow regime for plants is one that alters frequently (less than a two-year interval) between a turbulent eroding flow and a slow silting one, for as soon as one community is established it is destroyed by the change in flow type. The constant seasonal flow of the Skoenmakers River, therefore, provides ideal conditions for the establishment of some species.

The basic underlying processes controlling the riparian vegetation are therefore flow duration, flood frequency, flood intensity, depositional environments and variation within each parameter on different geomorphological processes which help to shape the fluvial landforms. This is due to the fact that vegetation types represent a gradient largely controlled by variation in frequency and duration of inundation from the channel bed to the top of the banks.

Research by Nilsson and Jansson (1995) indicated that the riparian vegetation structure was relatively uniform along free-flowing Boreal rivers but varies distinctly along regulated rivers due to differences in water level fluctuations of these unimpounded, but regulated rivers. They found that most abiotic variables, except water level fluctuations and some sediment variables (more coarse in regulated rivers), were similar for both regulated and natural rivers and therefore it can be assumed that the water level regulation and the availability of water to the riparian species represented *the* important factor.

5.4.4 Water availability

Riparian species have higher transpiration rates than terrestrial species and therefore require a permanent supply of water for at least part of the year (Van Coller and Rogers, 1996). Water availability can be seen as the primary factor limiting riparian vegetation abundance in semi-arid regions. Arid streams are water-limited on an annual or seasonal basis because of high discharge fluctuations. It was mentioned in the previous section that small changes in discharge and riparian water availability will lead to measurable changes in riparian vegetation abundance as riparian zones, especially those in semi-arid areas, experience short seasonal floods and long dry seasons when water availability is low, at least for shallow-rooted plants. The most important factors influencing the riparian water balance in any river section are the magnitude and timing of surface inundation and bank storage.

The impact of the IBT on the water availability and changes in the hydrological regime of the Skoenmakers River was presented in Section 5.2. The effect of the additional water supplied on the riparian vegetation of the recipient stream was evident from the comparison of the riparian zone width for selected sites along the non-regulated Volkers River and the regulated Skoenmakers River (Figure 4.28). Results indicated a definite increase in the riparian zones for each section of the regulated Skoenmakers River when compared to the non-regulated Volkers River. The impact of the increased flow in the post-IBT phase caused by the completion of De Mistkraal Dam is evident from the increase in the riparian zone width in the Skoenmakers River with between 10 and 20 metres for each of the sites. Taylor (1982), cited in Kondolf *et al.* (1987), developed a multiple linear regression model relating the width of the riparian corridor to average flow, gradient and the degree of channel incision. He found that average flow alone explained 44% of the variance in riparian strip width.

Tree species have the greatest richness along streams with intermediate flood magnitudes as these riparian species have little resistance to drought stress since sufficient water is needed to compensate for water losses due to transpiration. An increase in the density of *Acacia karroo* was evident from aerial photographs for the post-IBT phase and especially after the completion of De Mistkraal Dam. This is an indication of the influence of the additional water available on the vegetation, terrestrial as well as riparian. *A. karroo* is normally considered to be a terrestrial species but is often found in the riparian zone of semi-arid and arid rivers.

It must also be mentioned that it is difficult to measure direct influences of hydrogeomorphic processes on riparian vegetation, as these may be numerous, interactive and also complicated. Landuse activities and landuse changes close to the rivers, for example, can have a major effect on the riparian vegetation zone width. A decrease of the zone width for some areas was observed for the post-1987 phase. This is due to riparian vegetation clearance of the area for cultivation. The additional water from the IBT had increased the capacity of the river for this purpose.

Analyses of aerial photographs indicated that areas of cultivation showed an increase for all three sections along the Skoenmakers River and, as a result, a decrease in the riparian vegetation density was noticed due to riparian vegetation clearance in these areas. This is especially true for the upper reaches of the river where riparian vegetation (especially tree species, *Acacia karroo*) has been cleared to the extent that virtually no riparian zone is left.

The influence of the riparian vegetation on the geomorphology was most evident in areas where stability of the banks was influenced by the occurrence of high degrees of undercutting. It was observed in especially the upper reaches of the regulated river that the weight of the riparian trees caused bank collapse in localised areas and, therefore, general instability of the river banks can be seen as the main influence of the riparian vegetation on the geomorphology.

5.5 Conclusion

The influence of the IBT on the different river components was quite evident from this study. Due to the complex interrelationships between hydrology, geomorphology and riparian vegetation, any change to any of these components will lead to a change to one or both the other components (See Figure 5.2).

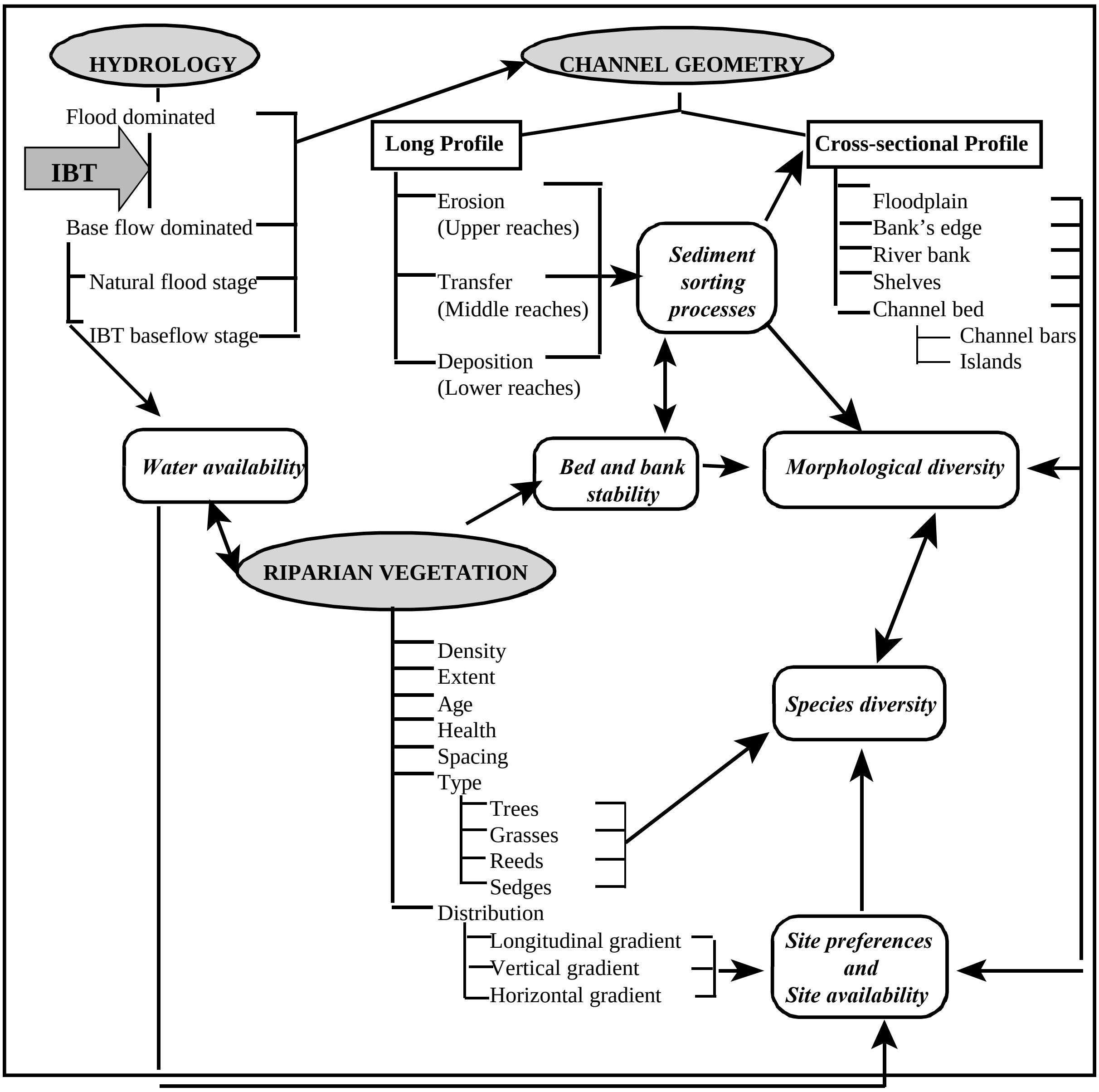

Figure 5.2: Schematic presentation of the influence of an IBT on the components of the recipient stream.

It was obvious that the dramatic change in the hydrological regime of a former ephemeral stream into a perennial river had far-reaching consequences and more detailed studies over longer periods are necessary to address each component separately, especially the complexities of the vegetation. The long-term effect on and development of geomorphological diversity and riparian communities along the regulated river is not known as this study on the morphological transformation and vegetation succession after regulation addressed the changes over a few decades only.

Chapter 6: Conclusions

6.1 Overview of study

River systems consist of numerous interrelated components and therefore a holistic approach is needed when assessing the influence of an outside disturbance on these delicate natural ecosystems. The change in the hydrological regime of the Skoenmakers River from an ephemeral stream to a perennial river had dramatic impacts on the physical and ecological characteristics of the river. This change in the hydrological regime directly influenced the channel geometry, i.e. the long profile as well as the cross-sectional profile. The influence on the riparian vegetation's composition and spatial distribution was found to be either direct (eg. loss of species caused by inundation) or indirect (eg. loss of species due to loss of suitable regeneration sites).

The most prominent changes to the channel of the Skoenmakers River was the incision of the channel bed in the upper reaches to such a degree that the bedrock has been exposed. Other changes to the channel due to the IBT include an initially wider active channel zone (increased width), armouring of the bed due to the removal of finer sediment, more bed material further downstream due to sedimentation, and decreased lateral stability of the channel.

The indirect impact of the IBT on the riparian vegetation of the regulated river indicate the complex interrelationships that exist between geomorphology and riparian vegetation and shows that any change to the basic underlying processes of any of the river system's components will affect the other components as well. The strongest link between geomorphology and ecological functions exists at morphological unit level. At this level the channel morphology determines the habitat conditions by providing the physical structure. Morphological diversity of the cross-sectional profile was found to be of major importance.

Morphological units such as shelves and mid-channel bars was found to have a stabilising effect on the river channels geometry. This effect on the stability of the channel can be direct through the enhancement of deposition of sediment or indirect by providing additional habitat for riparian vegetation growth and therefore an enhancement of the deposition of finer materials and therefore stability of the river channel.

The absence of shelves in the Volkers River suggests that they are related to present flow condition in the Skoenmakers River. Field observations indicated that the deposits on the shelves were recent and therefore suggests a flow that overtop these features from time to time during higher baseflow conditions (more than five cumecs). It might also be a result of rejuvenation of the channel bed, i.e. incision of the bed into material from upstream which was deposited in the post-IBT phase. More detailed investigation is needed on the formation of these features and it can only be speculated at this stage on how these important morphological units were formed.

Sediment deposition and/or removal were found to be the major underlying factors that have changed due to the increased baseflow of the Skoenmakers River. The response of the processes of deposition and erosion to the IBT differ for the three different river sections, upper, middle and lower reaches. The most dramatic changes in the channel geometry as a result of sediment sorting processes had occurred in the upper reaches of the regulated river below the IBT inlet.

An increase in the width and depth of the regulated river was measured in the upper reaches due to the high degree of erosion and incision. The change in the hydrological regime at the top of the regulated river's system from low frequency, high magnitude flood events to a constant baseflow was responsible for the dramatic changes in the geometry of the channel. The post-IBT channel is now formed by the constant baseflows and the severe erosion and incision occurring in the upper reaches can therefore be related to the increased baseflow which is higher than the natural flood flows at the top of the system.

A comparison of similar sites in the non-regulated Volkers River with sites in the middle reaches of the regulated Skoenmakers River shows the formation of shelves as the only major difference in this section of the regulated river. High degrees of sediment deposition in the lower reaches of the regulated river led to a decrease in the average channel depth. The lower reaches of the regulated river were able to 'absorb' the impact of the IBT much better than the upper reaches.

Erosion and deposition play a major role in the morphological diversity of the physical habitat which, in turn, was found to affect the diversity of the riparian vegetation. It was evident from analysis of quantitative data that an increase in the diversity of the physical habitat along the cross-sectional profile led to an increase in the species diversity of the riparian vegetation.

The spatial distribution of the different riparian vegetation types (grass, reeds, sedges, etc.) was found to be influenced by the type of sediment present, the distance away from the channel and elevation above the water level. It was found that woody species prefer distances further away from the active channel and therefore also higher elevations above the water level. Sedge species were present at sites where a higher percentage of finer sediment was observed, especially where shelves have been formed. The presence or absence of sedge species could therefore be linked to site availability.

The availability of suitable sites for regeneration and establishment of riparian vegetation species was strongly influenced by the change in the hydrological regime. Increased erosion in the upper reaches of the regulated river caused the introduction of more sediment into the river system downstream. Deposition of this additional sediment created new sites for the establishment of species such as grass and sedges.

On the other hand, the erosive force of the transferred water led to the loss of suitable habitat. This was evident in the upper reaches of the Skoenmakers River where severe erosion and incision of the channel bed and banks were observed. It was found that a strong link exists between the number of riparian vegetation species and the number of morphological units along the cross-sectional profile, and therefore the availability of sites.

The influence of the IBT on the Skoenmakers River in terms of the composition of the riparian vegetation was evident from the greater average number of species for the regulated river. This increase in the number of species was found to be related to the introduction of sedge species to the former ephemeral system as a result of the available water. A comparison of the importance percentages in terms of the different vegetation types, trees, grass and sedges clearly indicated a lower value for woody species along the regulated Skoenmakers River in comparison to the non-regulated river. On the other hand, significantly higher importance percentages were recorded for grass and sedge species along the regulated river when compared to the non-regulated Volkers River. Sedge species values more than doubled along the regulated river.

It is important to keep in mind that sedge species normally establish near the water's edge. Due to the lack of water in the ephemeral Volkers River, except for the lowermost site where return flows from irrigation is available in the channel, no suitable sites for regeneration exist and therefore explain the absence of this vegetation type in the Volkers River. It is therefore evident that water availability can be seen as one of the primary factors limiting riparian vegetation community composition and spatial distribution in a semi-arid region such as the Karoo.

The effect of water availability was most evident for the woody species of the regulated river. This vegetation type has increased along the regulated river for the post-IBT period due to the availability of water on a regular basis to the otherwise dry stream. Riparian vegetation needs seasonal flows to maintain its structure and therefore the constant supply of water to a normally ephemeral Skoenmakers River system is of great importance.

It can be concluded that the constant seasonal flow of the Skoenmakers River provides ideal conditions for the establishment of some species, eg. grasses and sedges. The steady change in the vegetation community composition of the regulated Skoenmakers River in terms of the grass and sedge species can be linked to the effects of the raised water level in the post-IBT phase.

6.2 Future research

Prior to any decision to proceed with a given project, the potential range of impacts of major IBTs must be clearly identified and carefully evaluated. It is important, therefore, to consider all the impacts (direct and indirect) that are affecting the social, economical as well as the environmental aspects. Much greater knowledge is needed on the dynamics of natural processes that would be affected by IBTs.

The need exists for an integration of ecological thinking into the geomorphological theory for the development of a better communication between different river researchers. The statement of Gregory and Gurnell (1988:36) clearly indicate the awareness of researchers on this topic: "...if we can understand the precise way in which vegetation affects river channel form and process, we will be able to manage the rivers of the future more effectively...". More than a decade down the line, the ecological component of the river system, and in particular the riparian vegetation, is only starting to be addressed. Future research will have to concentrate more on the specific relationships between the different components of the whole river system. The different aspects addressed in this study should be studied individually in more detail if a clear understanding of the effect of water transfers on the river system is to be accomplished.

"River regulation is not only a matter of hydraulic calculations. It is essential to develop a knowledge of biological functions through a fine analysis of the whole stream according to hydro-ecological criteria." (Lachat, 1996:693). This statement is widely recognised in the assessment of outside influences on today's river systems and it is evident that researchers have come to realise the importance of assessing the physical and ecological components of rivers. It was found, however, that a lack of knowledge on the effects of disturbances like IBTs to the riparian vegetation of the recipient streams exists.

Most studies on the ecological effects of IBTs concern invertebrates and fish. Environmental impact assessments of IBTs up till now lack knowledge of the impact on riparian vegetation. Future research should focus on establishing and ecological database to improve the design and operational characteristics of IBTs. Once this is in place, river regulation can be approved by considering the effect on the river's ecological integrity and biodiversity as well.

6.3 Conclusion

Due to a lack of detail in pre-IBT data, a comparison of natural and regulated rivers were used to indicate any changes brought about by the IBT. This *comparative study* method was also used by Nilsson *et al.* (1991) and gives one an indication of the degree of disturbance in the regulated river system. This kind of pre-test/post-test approach, however, is not without difficulties.

River systems are dynamic, constantly changing over time, and therefore it is possible that other changes occurred at the same time as the IBT. It is therefore evident that these changes (and not the IBT) could have been responsible for the change in the dependant variables of geomorphology and vegetation. This is particularly true for river morphology and riparian vegetation when a long period of time has elapsed between the pre- and post-tests. The 20-year period in which the IBT has been active in the Skoenmakers River could therefore be of major importance in this study and should be kept in mind throughout the research process of data collection, analysis and interpretation.

The increase of the diversity (especially that of the riparian vegetation) for the regulated river located within a semi-arid environment was a matter of concern. Semi-arid and arid river systems have a unique diversity and it is therefore evident that the changes brought about by the IBT can be viewed as a negative impact on the diversity on a regional scale. The unique characteristics of a former ephemeral stream has drastically been altered to that of a perennial river and the question should be asked if this is problematic from a biodiversity point of view.

An important factor evident throughout this study was that the effects of IBTs on the physical and ecological components of a river system differ from the effects of dams on rivers. In most cases, impoundments result in a reduction of water flow for the recipient stream (Church, 1995 and Fergus, 1997) whilst water transfers lead to an increased flow within the recipient stream as was the case of the Skoenmakers River. River regulation by IBTs is often far more complex than regulation caused by the storage of water. The effects of a water transfer depend on the amount of water transferred, the duration and season of transfer and the quality of water. It was evident from this study that understanding of the long-term effects of river regulation necessitates large-scale quantitative studies. Human impacts must be recognised and the effects minimised but it must also be realised that change is an inherent characteristic of fluvial landforms due to the dynamic nature of these systems.

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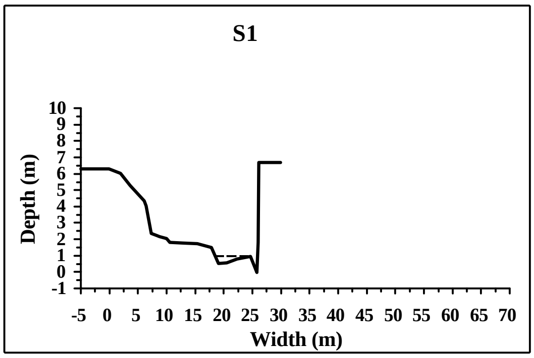
Appendix 1: Cross-sectional profiles for each site

SKOENMAKERS RIVER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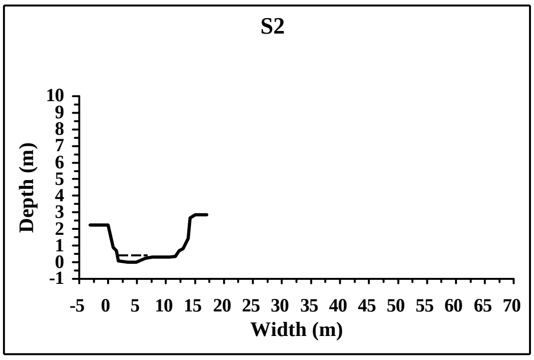
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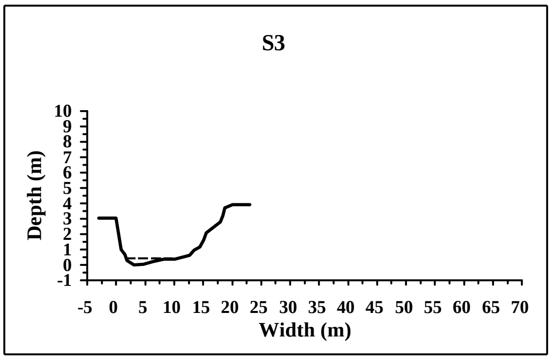
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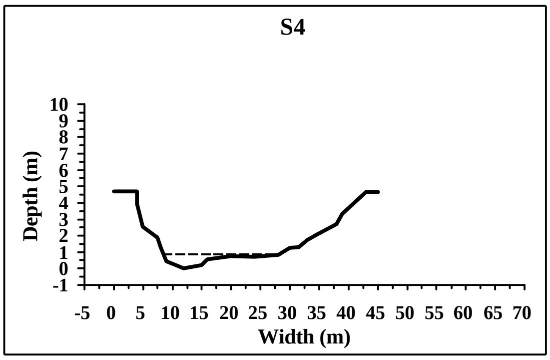
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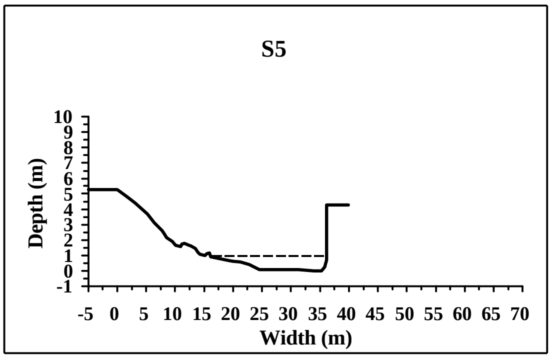
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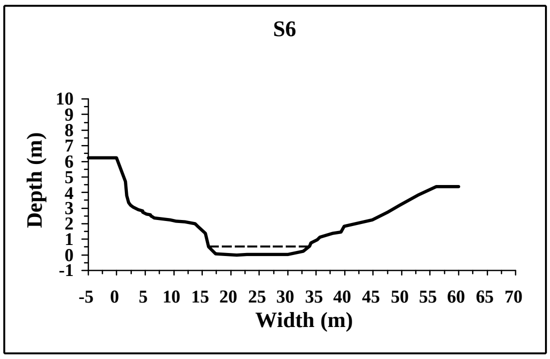
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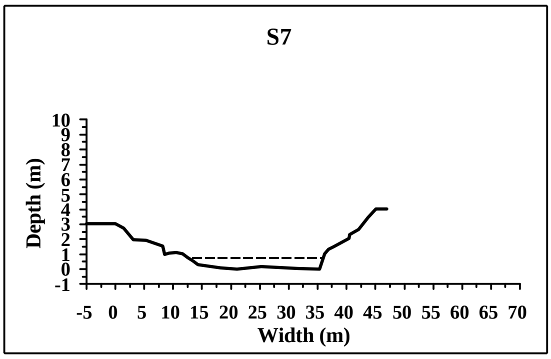
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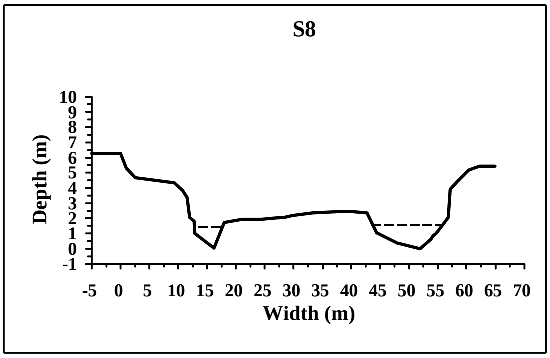
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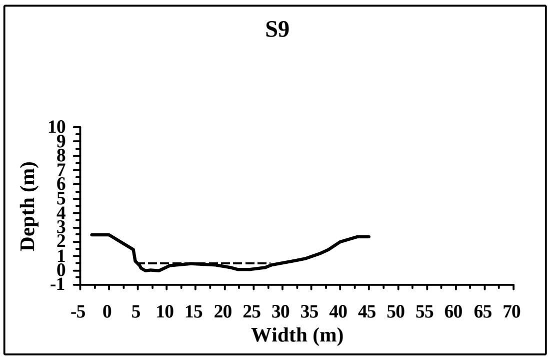
---------Water level at time of survey

SKOENMAKERS RIVER (Continued)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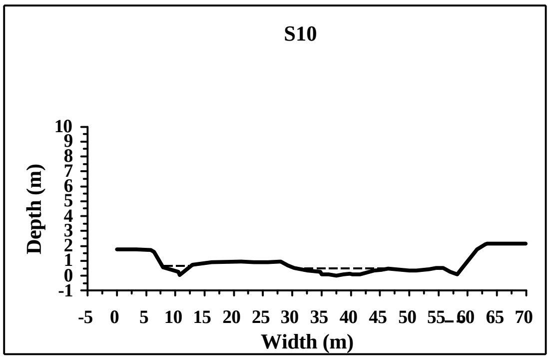
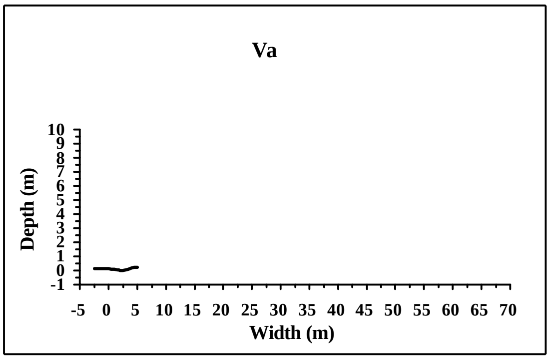

S10

VOLKERS RIVER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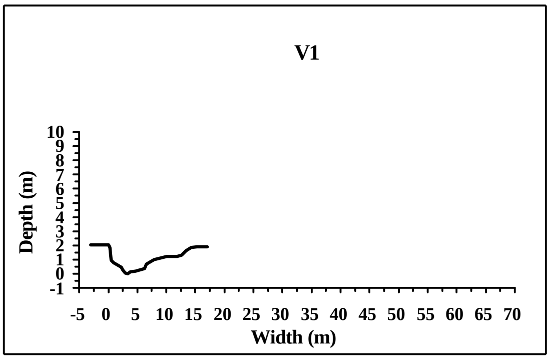
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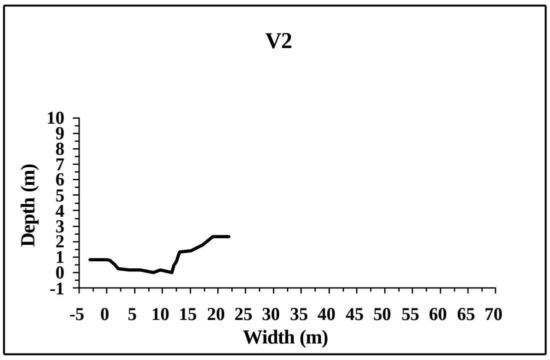
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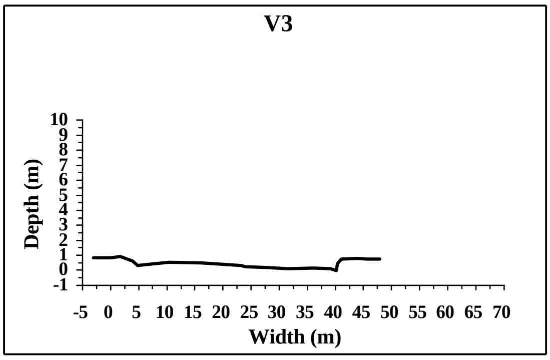
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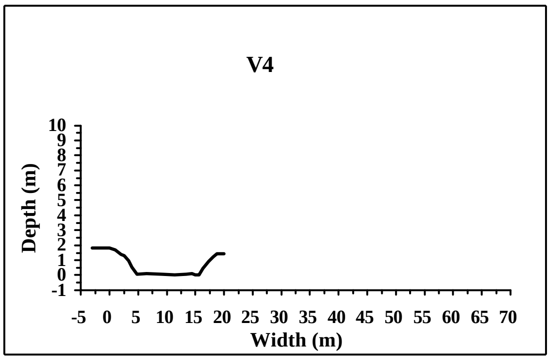
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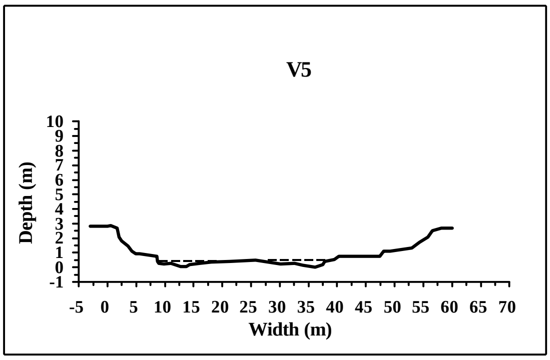
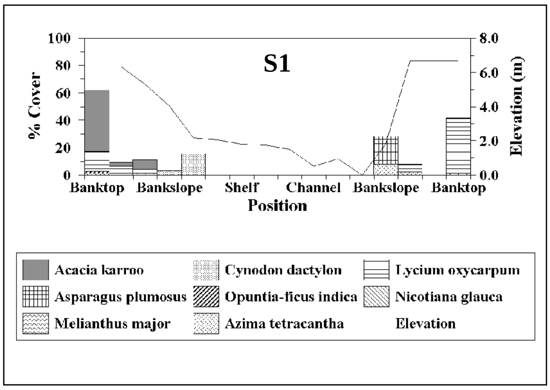
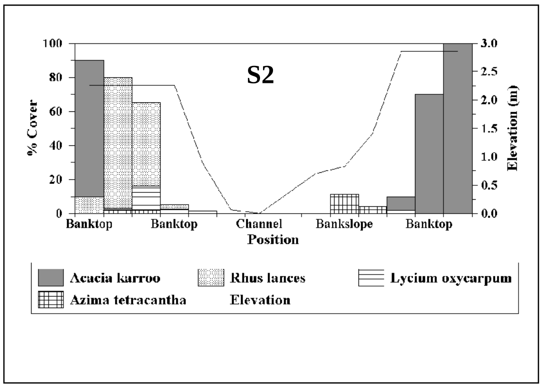
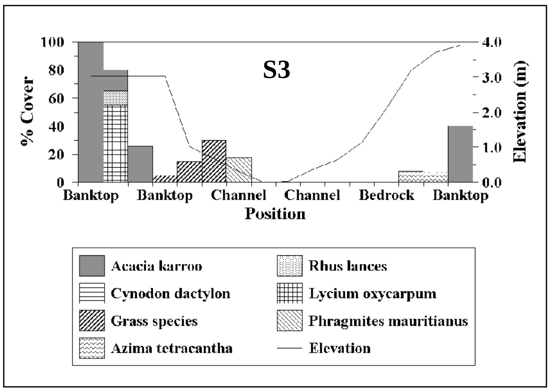

V5

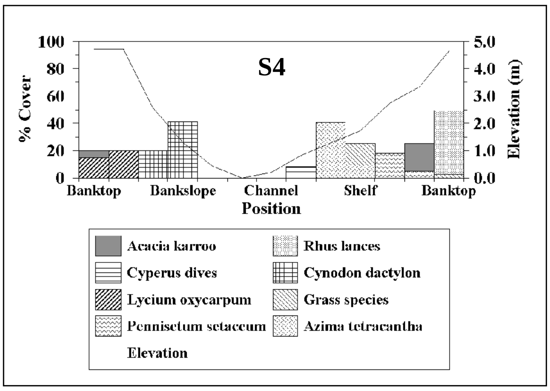
Appendix 2: Belt transects for the riparian vegetation at each site

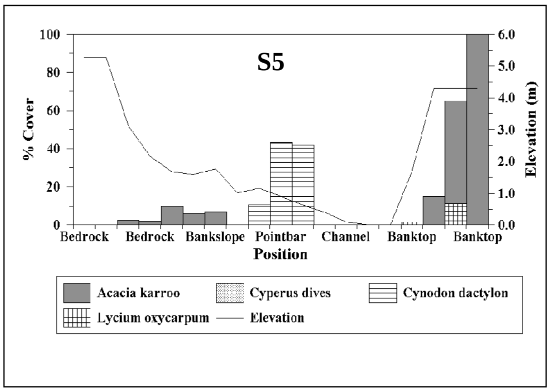
SKOENMAKERS RIVER

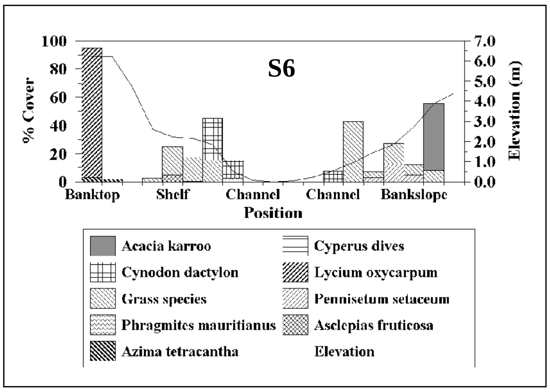


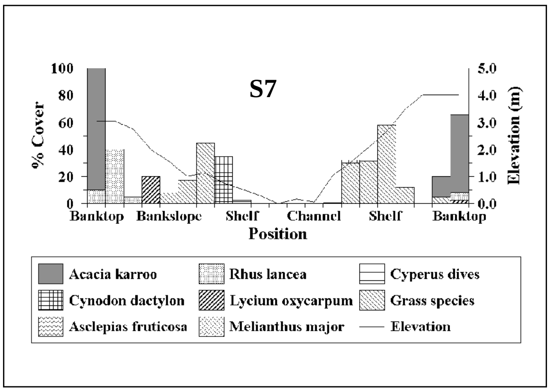


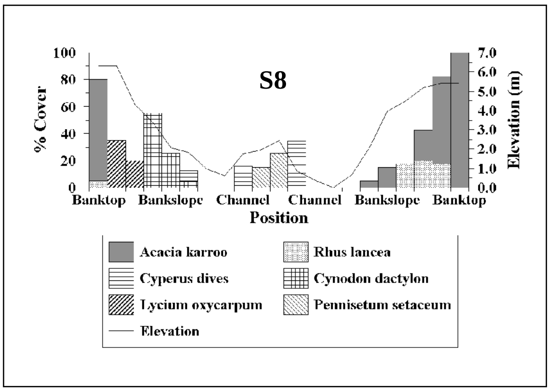












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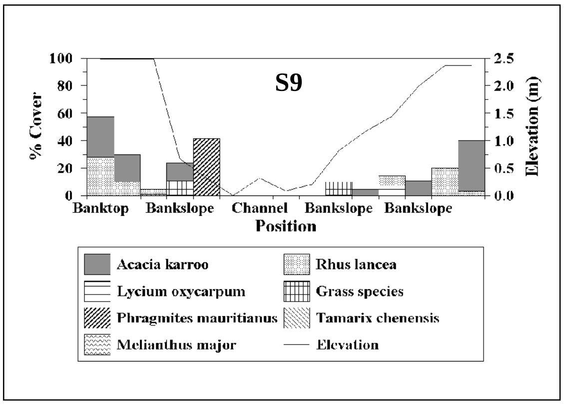
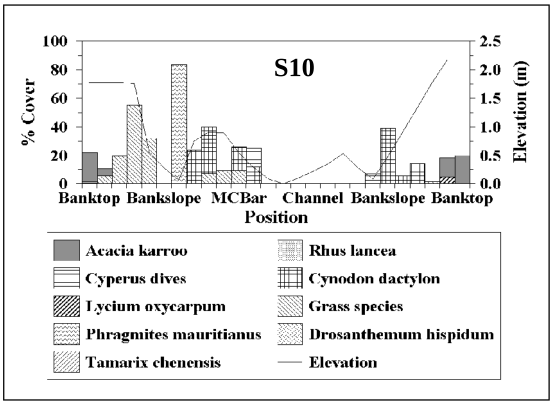
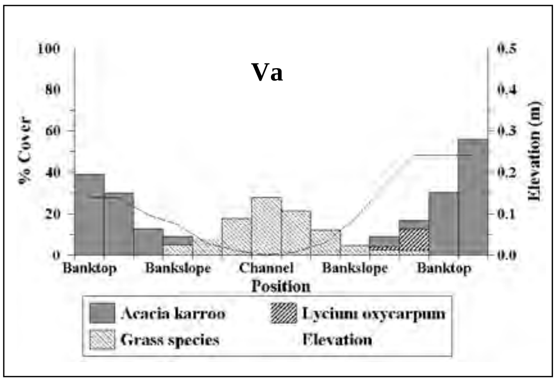
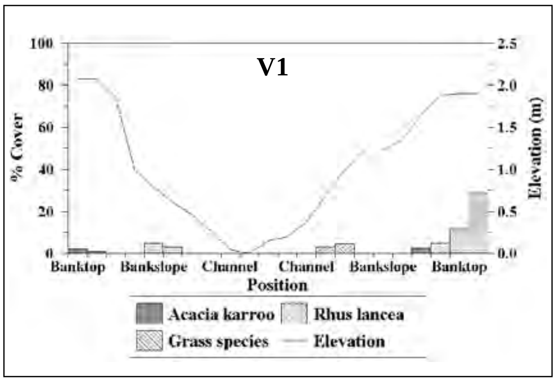
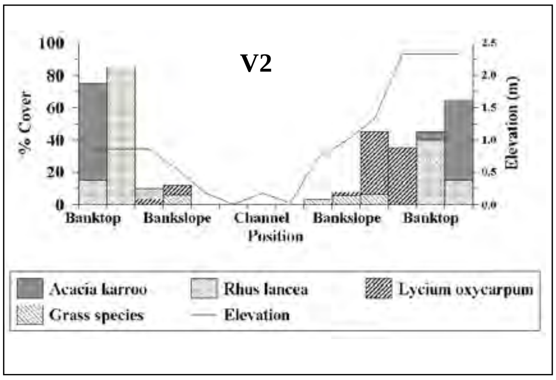


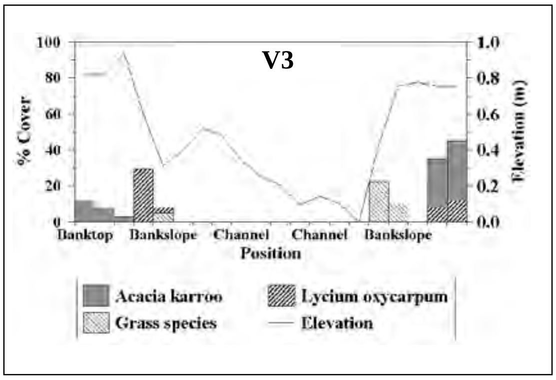


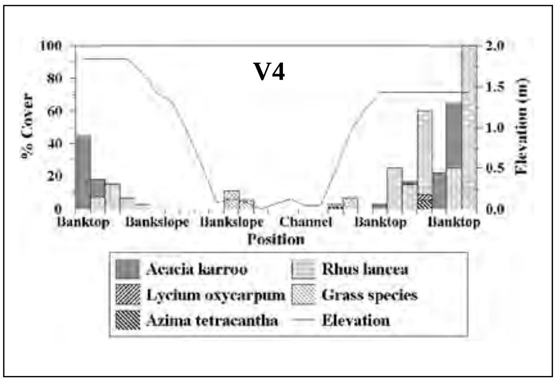
VOLKERS RIVER

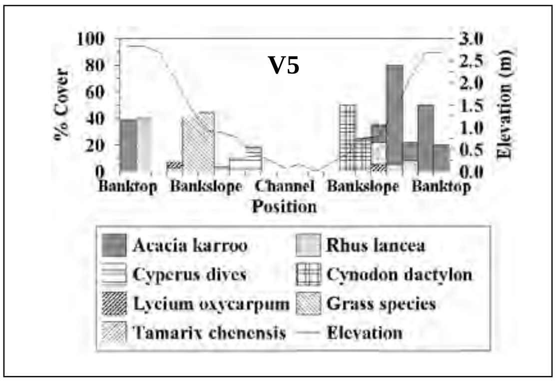






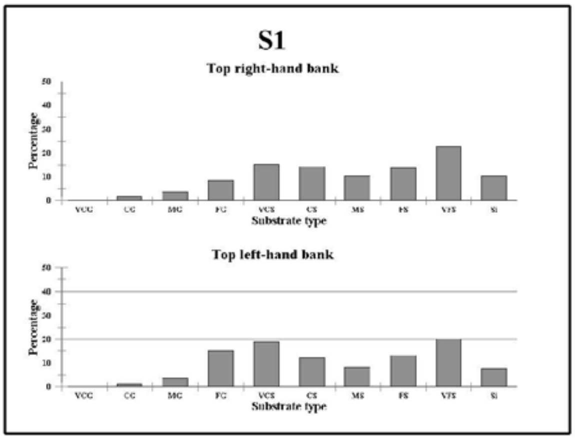


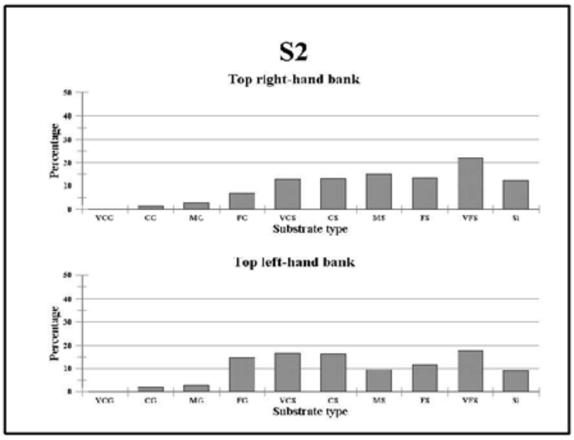


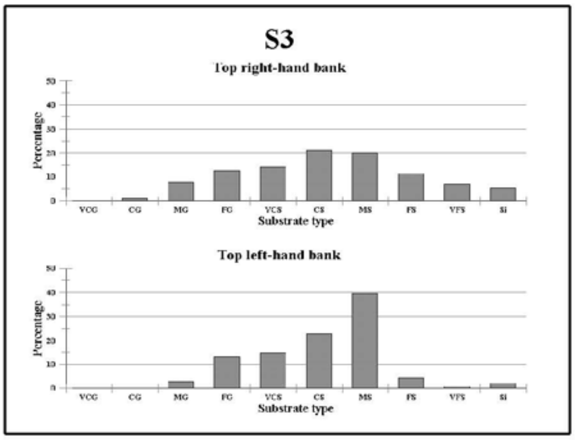


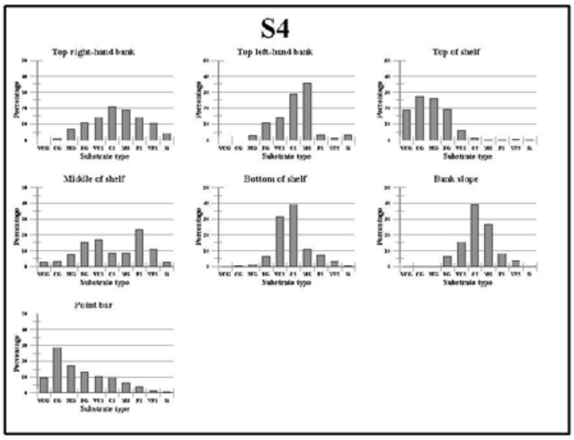
Appendix 3: Histograms constructed from sediment sample analysis

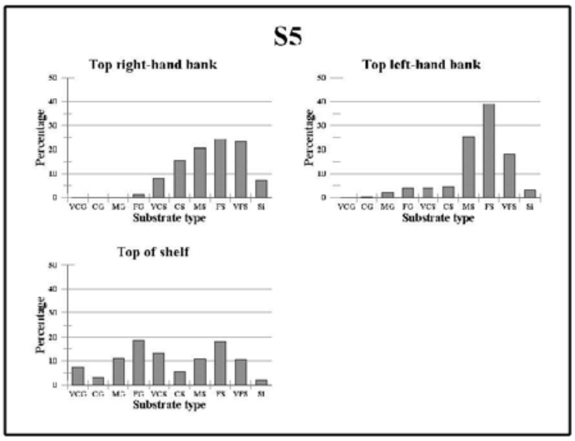
SKOENMAKERS RIVER

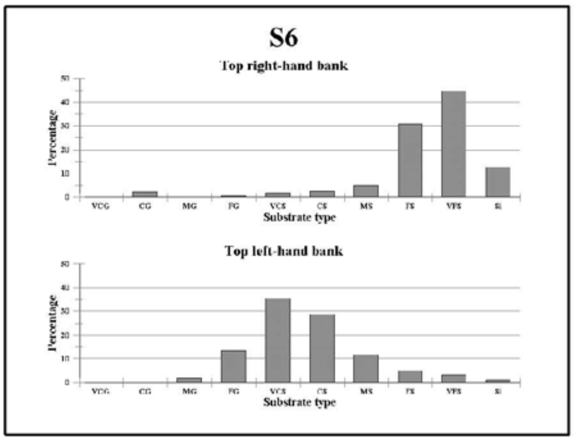












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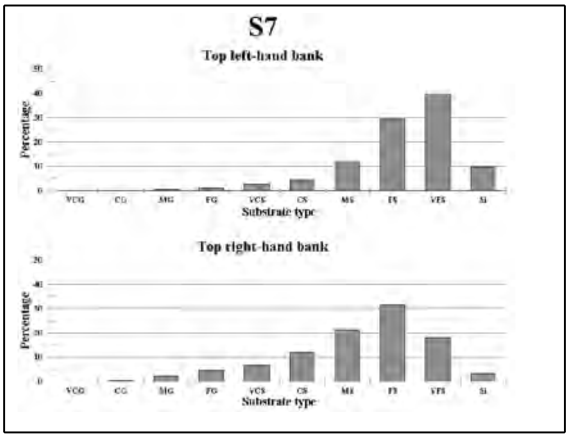

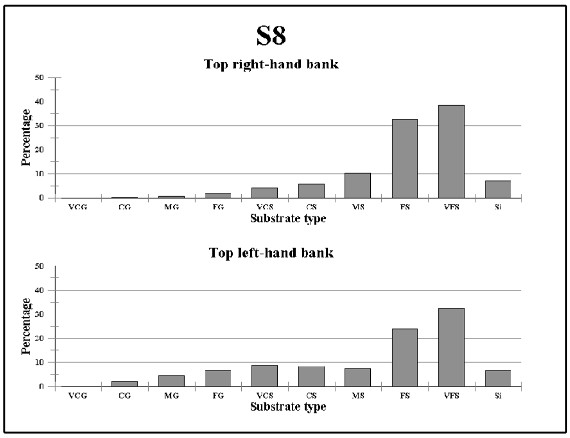

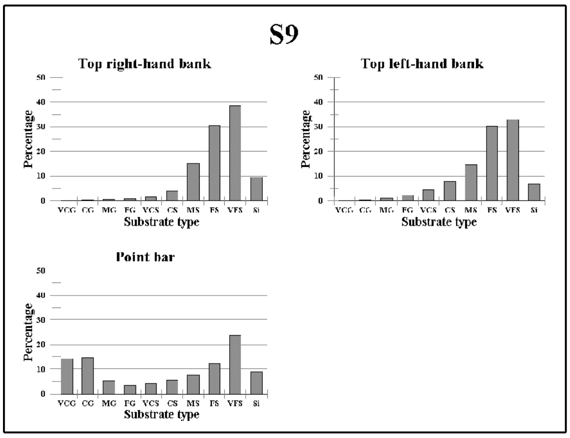

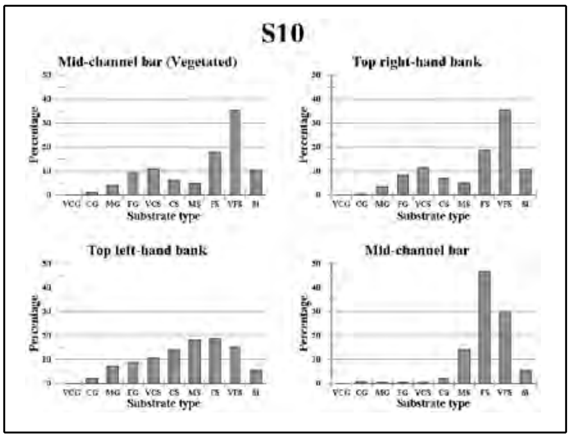

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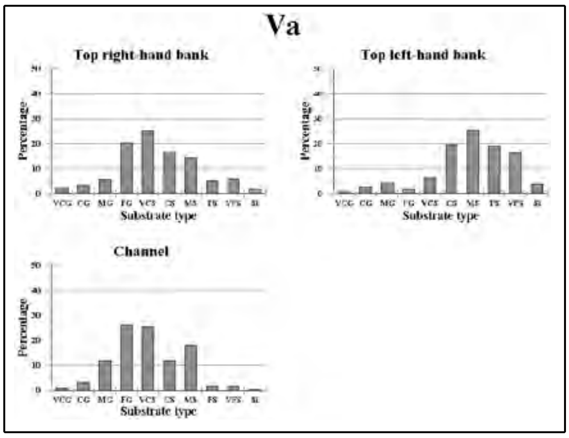

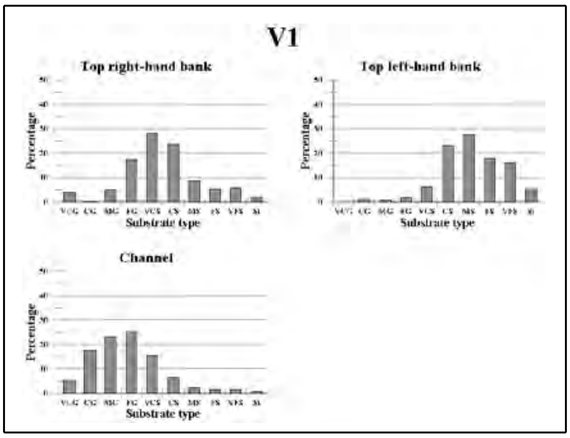

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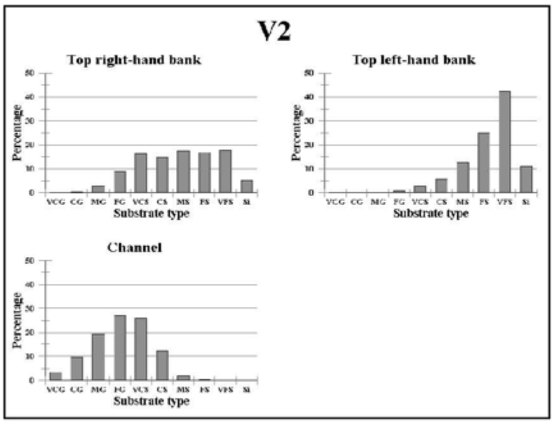

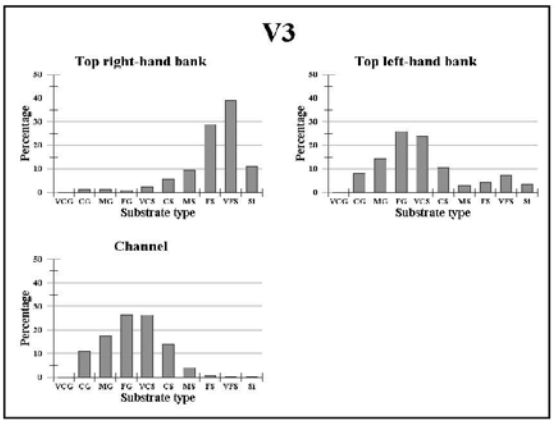

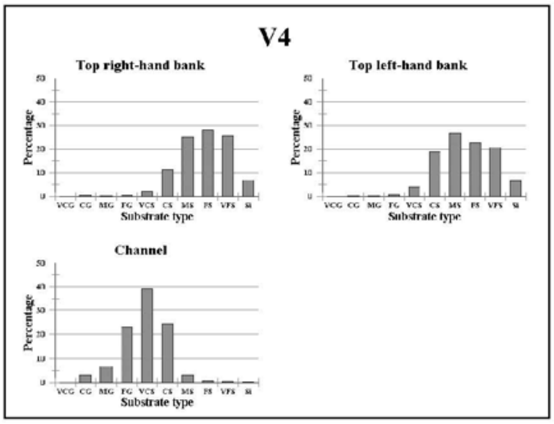

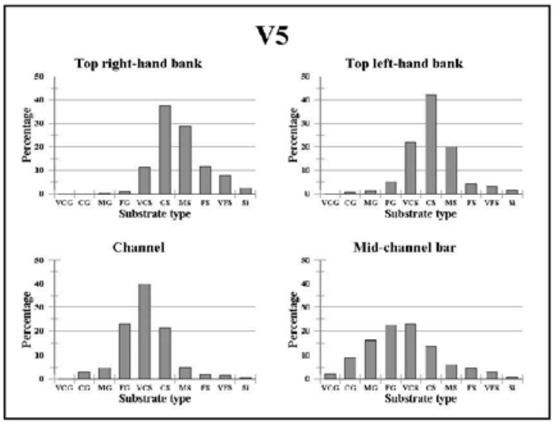

Appendix 4: Data sheet for qualitative assessment of riparian vegetation conditions

RIVER:_________________ **LOCALITY: Reach:_______Site:_________** **DATE:________________**

BANK:_________

VEGETATION PARAMETERS											
Species		**Type**	**Diversity** (MS/M/C)	**Density** (S/M/D)	**Height** (S/M/T)	**Extent** (W/M/N)	**Health** (H/F/P)	**Age** (I/M/O)	**Spacing** (C/Cl/W)	**Position** (BB/MB/TB/B/T)	**Remarks**
Name	**I/E***										

***Explanation of abbreviations to follow.**

ABBREVIATIONS

Type

G	Grass
R	Reed
S	Shrub
T	Tree
Su	Succulent
Se	Sedge

Position

BB	Basal bank
MB	Mid-bank
TB	Top bank
B	Bar
T	Terrace

Diversity

MS	Mono stand
M	Mixed
C	Climax

Health

H	Healthy
F	Fair
P	Poor

Species

I	Indigenous
E	Exotic invasive

Density

S	Sparse
M	Moderate
D	Dense

Age

I	Immature
M	Mature
O	Old

Extent

W	Wide
M	Medium
N	Narrow

Height

S	Short
M	Medium
T	Tall

Spacing

C	Continuous
Cl	Close
W	Wide

Appendix 5: Data sheet for plot sampling of the riparian vegetation

River:

Locality: Site: Bank:

Plot size: m^2

Total area sampled: m^2

Date:

Sediment type:

Riparian zone width: m

Plot ID	Species	Area (m^2)	Number of individuals	Remarks
Total				

Appendix 6: List of dominant riparian vegetation species identified

Species name	**Family name**	**Common name**
Acacia karroo	Mimosaceae	Sweet thorn tree
Asclepias fruticosa	Asclepiadaceae	Milkweed
Asparagus plumosus	Asparagaceae	Asparagus fern
Azima tetracantha	Salvadoraceae	Needle bush
Cynodon dactylon	Poaceae	Couch grass
Cyperus dives	Cyperaceae	
Drosanthemum hispidum	Mesembryanthemaceae	Dew plants
Lycium oxycarpum	Solanaceae	Honey-thorn
Melianthus major	Melianthaceae	Honey flower
Nicotiana glauca	Solanaceae	Wild tobacco
Opuntia aurantiaca	Cactaceae	Prickly-pear
Pennisetum setaceum	Poaceae	Fountain grass
Phragmites mauritianus	Poaceae	Common reed
Rhus lancea	Anacardiaceae	Karree tree
Tamarix chenensis	Tamaricaceae	Salt sedar
Other grass species	Poaceae	