THE IMPACTS OF WOODY INVASIVE ALIEN PLANTS ON STREAM HYDROGEOMORPHOLOGY IN SMALL HEADWATER STREAMS OF KWAZULU-NATAL

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ABSTRACT

In a water scarce country such as South Africa, the impact of Invasive Alien Plants (IAPs) on water resources is of particular concern. Alien plant clearing, which is predominantly a riparian problem, is seen as an integral component in improving the countries' water resource problems. Early research on the impact of IAPs on riparian zones focused predominantly on the impact upon water resource quantity. More recently awareness has been created of the need to understand the additional impacts of IAPs on the biophysical habitat of riparian zones. Scientific studies on the influences of woody IAPs on the hydrogeomorphology of riparian areas, studying the interaction of surface and subsurface hydrological processes with landforms and geomorphic processes, and the resultant effects on stream hydrology and ecology, have undergone little scientific investigation in the South African context. River and riparian zone rehabilitation is becoming accepted as having an essential role to play in the long term solution of water resource quality and supply problems and environmental health as a whole. Further research on the influence of IAPs on stream hydrogeomorphology is required for effective riparian zone management, and the sustainable restoration of ecological habitats and ecosystem goods and services delivery.

In this dissertation the impact of woody IAPs on streambank stability and channel form are investigated through field research utilising stream biophysical surveys. The current body of knowledge covering the impact of woody IAP invasions on streambank stability and channel form was investigated and a review of available stream survey methods performed to inform the development of a stream survey methodology for application in the study. The survey method developed was utilised to investigate the relationships between woody IAP invasions, streambank stability, channel form and riparian groundcover at two case study research sites located in headwater streams of KwaZulu-Natal. After applying the developed stream survey tools and fieldwork methodology, it was found that at the particular sites utilised in this study, woody IAP invasion tended to result in channel incision and streambank instability. The developed stream survey fieldwork methodology proved adequate for the study, but had limitations which could be addressed through further research to improve results confidence and the applicability of the method.

PREFACE

The work described in this dissertation was carried out in the School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, Pietermaritzburg under the supervision of Professor Graham Jewitt.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others it is duly acknowledged in the text.

DECLARATION

I, ………………………………………. declare that:

1. The research reported in this dissertation, except where otherwise indicated, is my original research.

2. This dissertation has not been submitted for any degree or examination at any other university.

3. This dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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Signed: ………………………………………
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Prof Graham Jewitt

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1. INTRODUCTION

South Africa has a long history of problems with invasive alien species. In an assessment of alien invading plants and water resources in South Africa Versveld *et al.* (1998) estimated that Invasive Alien Plants (IAPs) in South Africa covered an area equivalent to the size of KwaZulu-Natal. However this area of invasion was primarily concentrated along the river courses of South Africa as alien invasions are arguably a riparian problem (Versveld *et al.*, 1998).

In a 1998 assessment of the distribution of IAPs in South Africa Versveld *et al.* (1998) found a total invasion extent of 8% for South Africa (including Lesotho), while KwaZulu-Natal had a higher total extent of invasion at 9.75%. However the authors noted the limitations of the IAP mapping assessment and stated that from personal observations and observers' comments the area invaded by IAPs may be as much as 2-3 times greater than the 9.75% value obtained for KwaZulu-Natal. South Africa's most widespread invasive alien tree (Dye and Jarmain, 2004), *Acacia mearnsii* (black wattle), is ubiquitous throughout KwaZulu-Natal, and invades most severely where water is plentiful, such as along watercourses and road verges. However following dispersal along rivers, *A. mearnsii* spreads into adjacent terrestrial habitats (Richardson and Kluge, 2008) including indigenous grassland and forest. *A. mearnsii* was introduced to South Africa in the middle 19th century to provide tanbark, woodchips, construction poles and firewood, and its introduction spread rapidly across KwaZulu-Natal through farmers and foresters (Henderson, 2001; WESSA, 2008).

River and riparian zone rehabilitation is becoming accepted as having an essential role to play in the long term solution of water resource quality and supply problems and environmental health as a whole. As a result the impact of IAP invasions on water resources, ecological habitats and the delivery of ecosystem goods and services has undergone much scientific investigation (van Wilgen *et al.*, 2008). Numerous studies have shown that, under most circumstances, removal of IAPs results in a general increase in streamflow and returns a stream to a more natural seasonal flow regime. However, scientific studies on the influences of woody IAPs on the hydrogeomorphology of riparian areas, and the resultant effects on stream hydrology and ecology, have undergone little scientific investigation in the South African context. Hydrogeomorphology studies the linkages of surface and subsurface water, and hydrological processes with landforms and geomorphic processes in temporal and spatial dimensions. As a result the discipline is well applied to the study of the interaction of, and interdisciplinary impacts of IAPs on riparian areas.

Macdonald (2004:22) stated that there is a need to "investigate the interaction of IAPs with other aspects of water quality, for example soil erosion rates, including river channel and bank erosion." In the early 1990s, after a study assessing the potential impact of IAPs on the geomorphology of river channels in South Africa, Rowntree (1991) stressed that further research on the influence of IAPs on stream geomorphology is required to guide truly effective riparian zone management. Since this study, little scientific work has been undertaken on this topic in the South African context.

The literature review portion of this dissertation reviews the findings of various researchers as to how IAPs physically influence riparian habitats, specifically with reference to the role of IAPs in degrading riparian and streambank landscapes to an extent that streambank stability and stream channel form is adversely affected. This topic is introduced by illustrating the many functions that riparian zones can perform and some of the possible consequences of a loss of riparian habitat integrity. Worldwide awareness of the functions and values of riparian systems has led many countries to perform inventories of threatened and valuable riparian areas. A database of stream habitat integrity is useful for environmental impact assessments, development planning and resource inventories. Thus a multitude of stream survey and aquatic health sampling techniques and methodologies have been developed, some of which could be applied to assessing the influence of IAPs on riparian zones.

1.1 Research Aims and Objectives

This dissertation forms a research study based on field research centred around field methods and tools developed after a review of relevant literature.

The key aims of this research study are to;

- refine an international river habitat survey method for application within South Africa, and
- develop a test case to implement the developed method in analysing the impacts of IAPs on stream hydrogeomorphology in small headwater streams of KwaZulu-Natal, South Africa.

These aims are achieved through the following objectives;

- investigate the current body of knowledge covering the impact of woody IAP invasions on streambank stability and channel form,
- review available stream survey methods and develop a stream survey methodology which can be applied to investigate the relationships between woody IAP invasions and streambank stability and form within headwater streams of KwaZulu-Natal,
- investigate the relationships illustrated by the data after applying the developed stream survey tools and fieldwork methodology, and
- discuss any shortfalls of the developed tools and methods, and suggest future needs.

The hypothesis of the study contends that, within the focus of this study, invasion of headwater streams by woody IAPs can result in;

- increased channel incision and bank steepening, and
- an increase in streambank instability.

1.2 Document Structure

Chapters 2 to 4 form a review of current literature to establish a base of understanding of the implications, processes and components involved in the invasion of riparian zones by Invasive Alien Plants. In Chapter 5 the approaches to stream surveying are assessed and selected methods of stream survey seen as applicable to this study are reviewed. Based on these findings, a method of stream survey for application in this study is developed and described in Chapter 6 following a description of the fieldwork sites and methodology. Chapter 7 provides an extensive analysis and exploration of the results of the various components of the fieldwork, which are then discussed in Chapter 8. Chapter 9 outlines final conclusions, analysis of the applicability of the findings, and suggestions with regards to future research needs.

2. RIPARIAN ZONES

The South African National Water Act (1998) defines riparian habitat (analogous to riparian zone in this context) as the physical structure and associated vegetation of areas associated with a watercourse where flooding and inundation occur at a frequency, and to an extent where the vegetation species, composition and physical structure are distinct from adjacent terrestrial (land) areas.

Riparian areas provide many valuable functions and services. Most of these functions either cannot be suitably replaced by man-made technologies or can only be substituted at an unviable cost. The deterioration of riparian systems often produces knock-on effects that result in negative impacts on other systems. However, natural systems do have some degree of resilience. The many roles that riparian areas perform within a catchment may not be obviously apparent. Thus many people do not realise the full extent of the influence of healthy riparian areas and the potential dangers associated with their degradation. It is generally accepted that these regions have a strong influence on the hydrological flows of a catchment, and that they are also extremely sensitive to land use change (Scott and Lesch, 1993; Dye and Jarmain, 2004). The cumulative detrimental effect of many successive mismanaged and degraded reaches of river may only be noticed further downstream or in many years time.

2.1 The Functions and Values of Healthy Riparian Systems

The ecology of a region encompasses the animals and plants of a region, how they interact with their non-living environment and the flow of energy and materials between them. Riparian systems often sustain an abundance of ecological diversity, mostly due to the general availability of water and the life forms sustained by it. The riparian ecosystem provides a habitat for a diverse array of plants and animals, both aquatic and terrestrial. Many of the plants and animals are specially adapted to live in riparian and wetland habitats and may not survive in other environments. Examples of indigenous aquatic wildlife that survive in riparian regions and wetlands are water birds, amphibians, reptiles, fish and hydrophytic plants (Wyatt, 1997). Riparian zones also provide valuable feeding and breeding refuges for many animal species. Riparian vegetation remains green for longer during winter, providing refuge and food for many species all year round. In addition, riparian areas play a pivotal role within the wider ecosystem and habitat of their surrounding region.

Properly functioning riparian systems allow for sediment settling and water filtering through vegetation or sediments at certain regions along a river, thus improving water quality. In addition, riparian zone vegetation can act as a buffer to limit potential harmful inputs from adjacent land use, such as pollution and soil erosion. Plant and animal aquatic life and associated biological and chemical processes within the riparian ecosystem also aid in the purification of water.

Riparian zones and wetlands play an important role in flood mitigation and streamflow regulation. Riparian and wetland vegetation is flexible and deep-rooted to help withstand the force of floodwaters and thus slow the velocity of floods. Riparian vegetation often grows densely on the streambanks and floodplains (Figure 2.1), which is where it plays a strong role in slowing floodwater velocities. In terms of streamflow regulation, wetlands act like sponges, slowly releasing water and producing more regulated flows (Maltby, 1991; Kotze *et al.*, 2005). Natural riparian banks and channel sides allow groundwater and hillslope seepage into the channel to maintain lowflows. Riparian vegetation is highly effective at limiting soil erosion by binding the soil, stabilizing the banks, dissipating current energy and trapping suspended sediments (Carter *et al*, 1978).

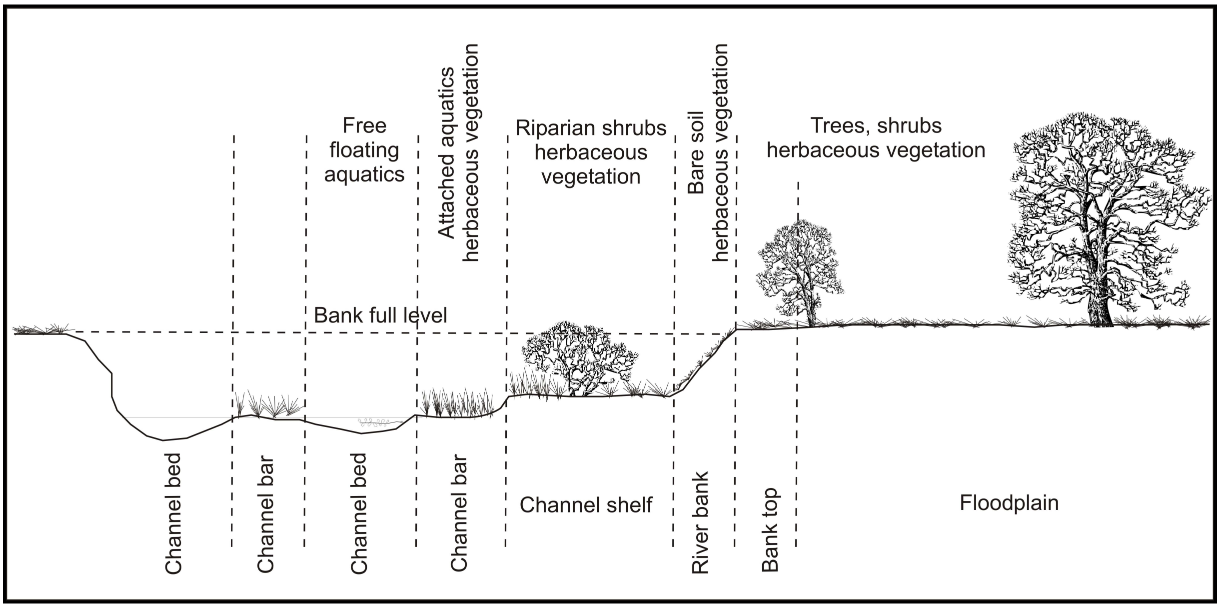

Figure 2.1 Geomorphic features of riparian zones (after Rowntree, 1991 and Hupp, 1990)

Riverine areas also have aesthetic and recreational value to society as a result of their natural beauty and open water. Bird watchers will commonly find an abundance of species, as well as a variety of unusual and rarely seen fauna. Riparian areas are also of great interest to biologists due to the density and diversity of fauna and flora. Thus riverine areas also have a high educational value. Other goods can potentially be harvested from wetlands, such as reeds for basket weaving or building materials, foods, natural medicines and grazing (Kotze *et al.*, 2005).

Riparian areas have a high economic value as a result of all of the above mentioned ecosystem goods and services that they provide (van Wilgen *et al.*, 2008). Economic value cannot be placed on these valuable services, such as the maintenance of biodiversity, water supply or flood mitigation.

2.2 The Degradation of Riparian Zones

The over-utilisation of ecosystem goods and services can rapidly result in the destruction of the resource and the ecosystem as a whole. Resource over-exploitation through the harvesting of plants or animals, livestock grazing, sand, rock or mineral mining, water abstractions or clearing for agriculture or forestry all result in the degradation of riparian zones and wetlands. Modifying, redirecting, channelling or impounding rivers to reduce the risks associated with floods, to make way for urban development or to provide water supply also result in the widespread degradation of river systems. Landuse within the catchment also has the potential to impact heavily on the health of riparian and wetland areas. Amongst numerous other impacts, land use change can result in a change in surface water flow, subsurface water recharge, the volume of sediments and other pollutants entering the riparian areas, a change in adjacent biodiversity and the interconnectivity of natural habitats. Such impacts have the potential to alter the flood regime, winter low flows, water quality, hydrogeomorphology, biodiversity and ecological health of the riparian systems.

Riparian habitats are highly prone to invasion by IAPs due to their dynamic hydrology and opportunities for IAP introduction and establishment following floods (Holmes *et. al.*, 2005). Invasion by alien plants has the potential to cause many degrading effects on riparian zones. Alien plants commonly out-compete indigenous plants, which in the case of *Acacia mearnsii* (black wattle) and *Solanum mauritianum* (Bugweed) may result in a loss of groundcover beneath the infestation (Wells *et al.*, 1986). Loss of groundcover, through competition with alien plants or overgrazing and livestock trampling, not only leaves the soil susceptible to erosion but can also result in surface crusting. An absence of groundcover allows raindrops to strike the soil surface and dislodge small particles of soil. Under some circumstances these small particles flow into voids in the soil surface during infiltration. This eventually results in sealing off of all voids, thus excluding infiltration and causing soil surface sealing or crusting (Selby 1993; Beckedahl, 1998; Harden and Scruggs, 2003; Strunk, 2003). This surface crust produces rapid stormflows and further inhibits the establishment and growth of vegetation.

In all environments overgrazing results in less infiltration and increased overland flow, causing increased stormflow and flooding (Burt, 2001; Toy *et al.*, 2002; Strunk, 2003). An impact that has been shown to significantly reduce groundcover below trees, and thus promote soil erosion, is livestock trampling (Selby, 1993; Burt, 2001; Strunk, 2003). Toy *et al.*(2002) found that litter cover under most undisturbed forests is sufficient to prevent excessive erosion. However they state that grazing in farm woodlots often results in loss of the litter layer leaving a high potential for soil erosion. Therefore grazing should be managed to maintain the groundcover or should cease altogether in sensitive areas.

In addition to the removal of groundcover through grazing or trampling, livestock also promote erosion through soil compaction by trampling. Once again this limits infiltration and results in greater overland flows. Networks of livestock trails create preferential flow paths for surface runoff water, which can rapidly develop into erosion gullies, strongly degrading the soil quality and structure of the area (Beckedahl, 1998; Burt, 2001; Strunk, 2003).

3. INVASIVE ALIEN PLANTS

Current studies on the influences of IAPs on hydrology have been given renewed attention in South Africa post the National Water act of 1998. In a South African context, most investigations into the hydrological influences of IAPs have been on their streamflow reduction, as this topic addresses current issues of water supply deficits. However, many other influences of IAPs on hydrology and ecology are yet to be fully investigated. In 2004, van Wilgen (2004:9) remarked that "there remains a need to expand our fundamental understanding of the processes that underlie invasions and the effect that they have."

3.1 The Geographical Extent of Invasive Alien Plants in South Africa

Through an assessment of field records gathered from 1979 to 2000 of the invasion status, geographical extent and abundance of IAPs, the Southern African Plant Invaders Atlas (SAPIA) shows the following geographical distributions of IAPs (Henderson, 2007).

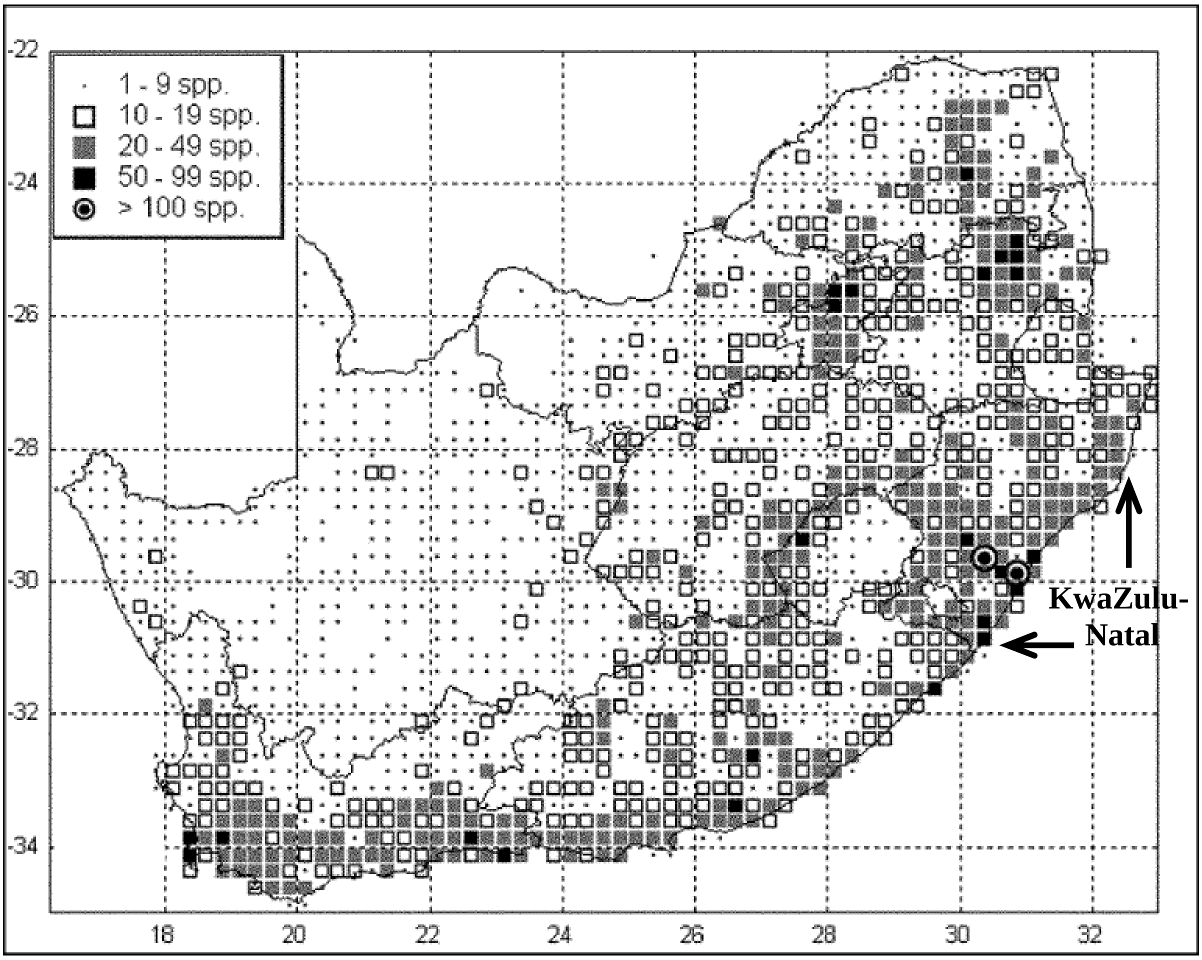

Figure 3.1 IAP species numbers per square of quarter degree grid (Henderson, 2007)

From Figure 3.1,which shows the number of IAP species per quarter degree square across South Africa, Swaziland and Lesotho, it can be seen that KwaZulu-Natal has a high number of species covering the majority of the province. Figure 3.2 shows the severity of invasion per quarter degree square based on the total weighted abundance of all species per quarter degree square.

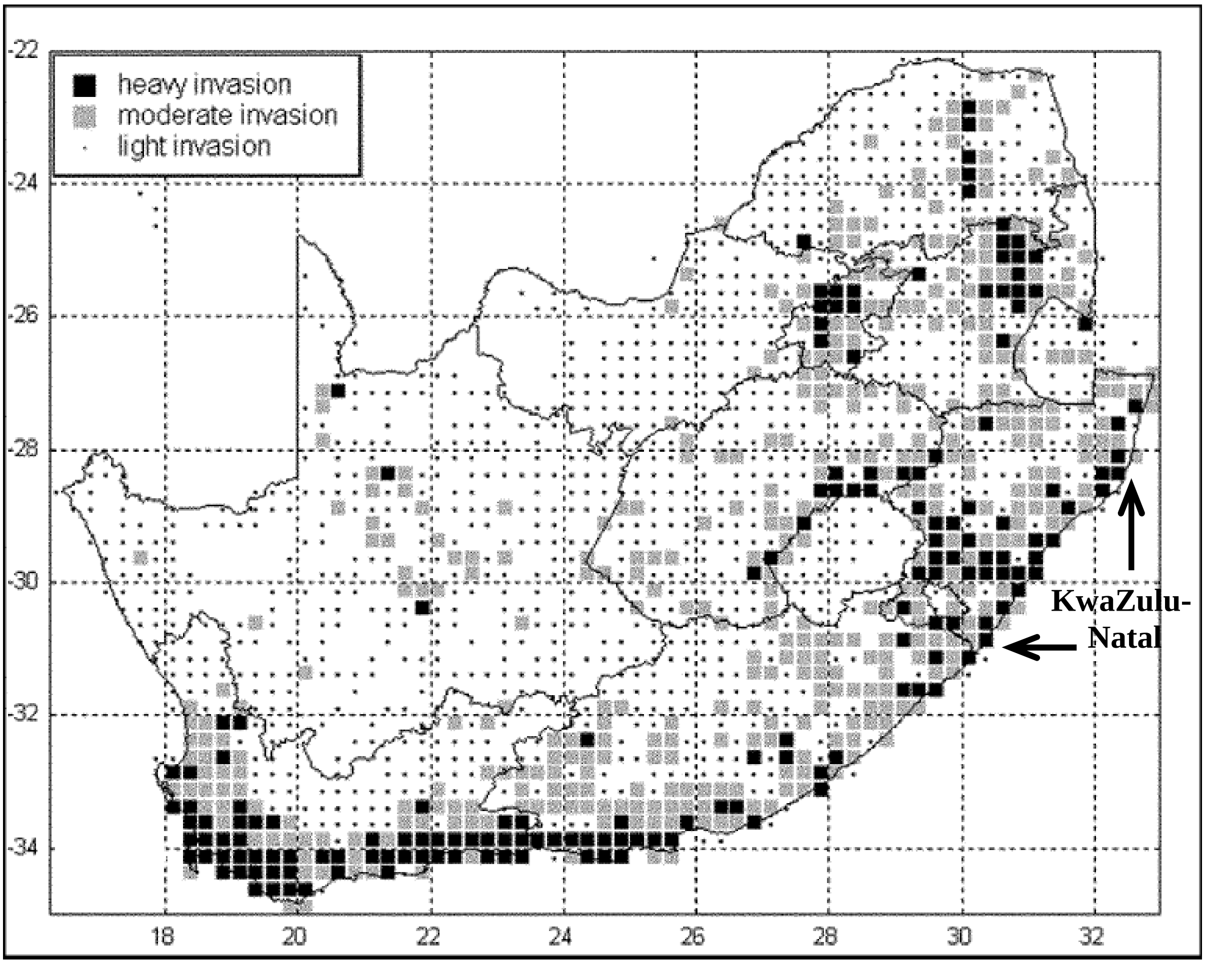

Figure 3.2 Severity of invasion per square of quarter degree grid (Henderson, 2007)

In relation to Figures 3.1 and 3.2 Henderson (2007) observed that the highest IAP species numbers and abundance corresponded with the regions of highest rainfall, urban development, and cultivation of agricultural and silvicultural crops (Henderson, 2007).

3.2 The Problem of Invasive Alien Plants

The study of fluvial geomorphology recognises two sets of variables important to controlling channel form:

- site variables which influence channel form, and
- catchment variables which determine the runoff and sediment regime.

Riparian vegetation is seen as a key site variable controlling channel stability and channel form (Rowntree, 1991). This relationship is explored in Figure 3.3, showing that riparian vegetation transformation as a result of IAP invasion has the potential to influence channel form. Rowntree (1991, pp28) stated that "wherever alien vegetation invades the riparian zone it can be expected that there will be some sort of impact on the physical structure of the riparian habitat." Transformer invasive species result in the transformation of a mixed indigenous community into a woody monoculture. Woody IAPs in particular, have a strong potential to cause channel modification. Their removal can induce significant soil erosion problems and cause streambank instability (Rowntree, 1991). In addition, the burning of dense stands of woody IAPs can lead to a significant increase in sediment yield from the catchment following rainfall events (Holmes *et. al.*, 2005).

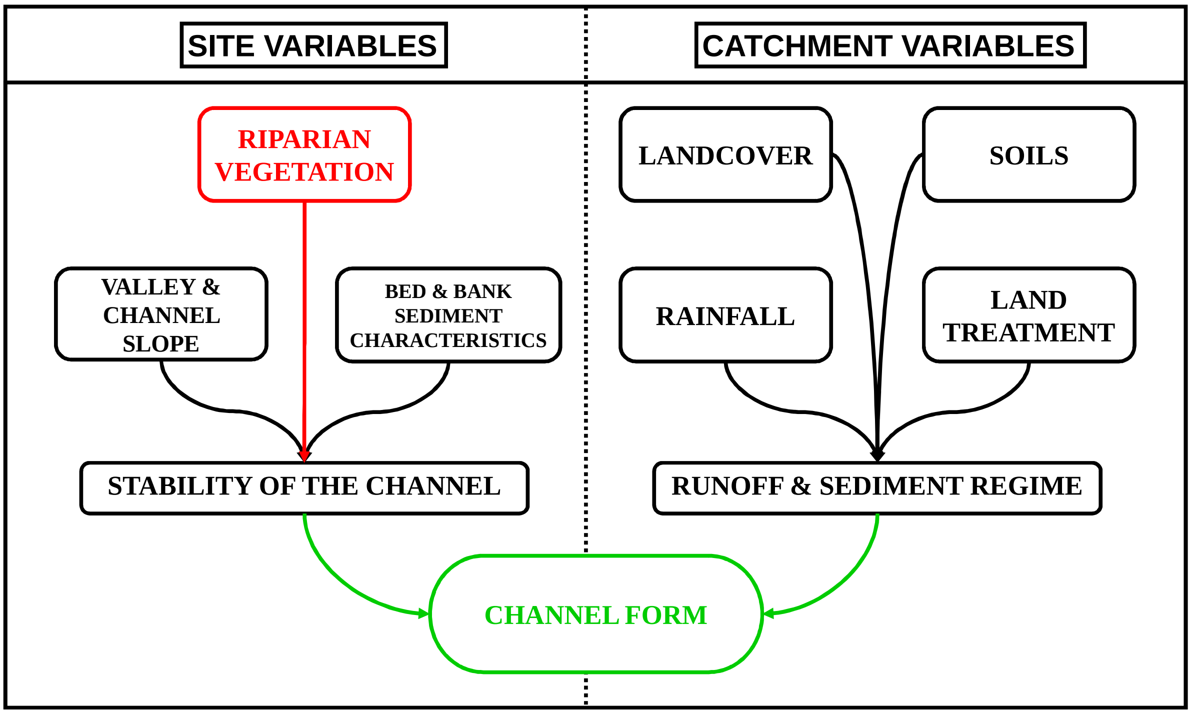

Figure 3.3 Relationship of key variables important to controlling channel form (for illustrative purposes - list of variables not all inclusive)

Turpie (2004) noted that benefits to IAP eradication from riparian zones often accrue later and go unnoticed or underestimated. Alien invaders directly and indirectly cause huge economic losses in terms of lost agricultural productivity and resources spent on weed control (Le Maitre *et al.*, 2004). Le Maitre *et al.* (2004) made an assessment that the economic impact of *A. mearnsii* invasion in South Africa gave a net present cost of R9.8 Billion. It is estimated that by 2003 the Working for Water programme had cleared about 12% of the country's IAPs at a cost of R1.95 Billion (Macdonald, 2004).

Abernathy and Rutherford (1998) are of the experience that indigenous riparian vegetation is increasingly becoming a favoured stream management tool. Numerous advantages highlight the necessity of the re-establishment of indigenous cover (Prinsloo and Scott, 1999; Campbell, 2000). Unfortunately riparian areas have a long history of mismanagement and abuse. While rehabilitation is necessary and possible, there are many difficulties involved. Most notable is the extent of the problem coupled to the economic costs of rehabilitation (Marais *et al.*, 2004). As a result the involvement of all stakeholders is imperative. To achieve long-term sustainability, ongoing maintenance and control will also be required (Campbell, 2000).

Woody IAPs provide a unique problem to riparian zones and river banks in comparison to herbaceous vegetation. In terms of riparian banks and floodplains Rowntree (1991) found that woody IAPs;

- can increase the weight upon the bank with related impacts on stability,
- deeper woody roots can improve bank stability (Figure 4.1),
- roots can extend into the channel flow, possibly resulting in scour and erosion,
- can interfere physically with channel meander and floodplain processes of scour and deposition,
- commonly introduce woody debris to the channel with various consequences,
- can introduce localised flow turbulence, particularly during flooding, which can result in erosion,
- are commonly unable to withstand the force of floods, are uprooted, causing destruction of riparian banks and floodplains resulting in erosion,

- commonly reduce the density of riparian groundcover, lowering the shear strength of the soils within floodplains and on riparian banks, resulting in lower resistance to floods, reduced flood attenuation and increased scour and erosion.

The potential impacts of woody IAPs are explored further in Section 4.2.

In the upland regions of KwaZulu-Natal three *Acacia* species, *A. mearnsii* (black wattle), *A. dealbata* (silver wattle) and *A. decurrens* (green wattle), along with *Solanum mauritianum* (Bugweed) are among the most widespread woody IAPs (Rowntree, 1991). *Rubus cuneifolius* (American Bramble) is also classified as a woody IAP and commonly invades open grasslands and disturbed habitats (Henderson, 1995). *R. cuneifolius* out competes grasses, is able to transform the local habitat and landscape, and restricts access (Wells *et al.*, 1986). *S. mauritianum* commonly invades along watercourses, in plantations, along roadsides and disturbed habitats (Henderson, 1995). *S. mauritianum* also out competes indigenous vegetation, is able to transform the local habitat and landscape, and is poisonous (Wells *et al.*, 1986).

3.3 The Extent of Invasion by *A. mearnsii*

In a classification study of IAPs Nel *et al.*(2004) identified 258 alien invasive plants in South Africa. *A. mearnsii* was one of the top three invaders by area, and was classified as most 'abundant' and 'very widespread.' Dye and Jarmain, (2004:40) went as far as to say that "Black wattle is one of the most widespread and significant invasive alien trees in South Africa." Henderson (2007) stated that *Acacia mearnsii* was by far the most prominent invasive species in a study area consisting of South Africa, Swaziland and Lesotho. More funds have been spent on the control of black wattle, by the Working for Water programme, than all other IAPs together (Nel *et al.,* 2004). Through an assessment of data from the Working for Water Information Management System (WIMS) Marais and Wannenberg (2008) calculated that from the period 1997/8 to 2005/6 the estimated overall cost of treatment for *A. mearnsii* came to R62.51 Million.

It is well known that *A. mearnsii* invades mainly along river courses (Gillham and Haynes, 2001; Esau, 2005), particularly in riparian zones in dense thickets (Dye and Jarmain, 2004), owing mostly to the seeds being water-dispersed (Macdonald and Jarman, 1985). Rowntree (1991, pp28) highlighted reasons, identified by Henderson and Wells (1986), that explain why riparian zones are most prone to infestation; i.e. "exposure to periodic natural and human related disturbances, the perennial availability of moisture, reliable dispersal by water and the role of streambanks as a seed reservoir." *A. mearnsii* also proliferates in disturbed habitats, such as road verges, gulleys, livestock tracks and on overgrazed lands (Macdonald and Jarman, 1985; Esau, 2005). The invasive tree is quick to establish itself once deposited on streambanks and depositional surfaces (Cohen and Brierly, 2000). However following dispersal along rivers, *A. mearnsii* commonly spreads into adjacent terrestrial habitats (Richardson and Kluge, 2008) including indigenous grassland and forest. *A. mearnsii* invades high mountain catchments where much of South Africa's water supply for major cities and industries comes from. Dye and Jarmain (2004) also stated that serious infestations occur in the higher rainfall regions of the country. The problem of IAPs invading mountain catchments and potentially reducing valuable domestic water supplies is a worldwide phenomenon (Harden and Scruggs, 2003).

A. mearnsii potentially has the strongest influence on river hydrogeomorphology as;

- the species readily invades along stream channels,
- the species produces high seed volumes which float down watercourses,
- being woody it can directly interfere with channel processes,
- being relatively shallow rooted it does not stabilise river banks, and
- having woody roots it does not protect the soil surface.

From a review of related literature an extensive list of potential advantages to the removal of *A. mearnsii* can be compiled;

Table 3.1 Potential advantages to the removal of *A. mearnsii* from catchments

increased groundwater recharge	greater access to land and resources
increased streamflow	easier access to manage livestock
possible improved low flows	livestock have easier access to water
restoration of natural flood attenuation	reduction in intensity of fires
less damming by woody debris	improvements in environmental biodiversity
more stable streambanks and channels	improved water quality
reduced soil erosion and nutrient loss	healthier aquatic life
reduction of losses in agricultural productivity	strengthened ecology
increased grazing land	improved natural aesthetic beauty
restoration of natural buffer zones to limit soil erosion and pollution reaching water courses	

(Rowntree, 1991; Bosch *et al.,* 1994; Beckedahl, 1998; Prinsloo and Scott, 1999; Burt, 2001; Gillham and Haynes, 2001; Gorgens and van Wilgen, 2004; Richardson and van Wilgen, 2004)

3.4 The Effects of Invasive *A. mearnsii* on Streamflow

Dye and Jarmain, (2004) stated that it is widely accepted that the clearing of dense stands of *A. mearnsii* from riparian zones leads to improved catchment water yields. As mentioned previously it is in high mountain catchments of high rainfall where *A. mearnsii* infestations are most prolific. It is also in these very places where the potential of the alien invasive to reduce streamflow is highest. This is because the invasive vegetation typically has the highest transpiration rates in an environment where it has a constant year-round supply of soil moisture (Dye *et al.*, 2001). The highest streamflow reductions will be from *A. mearnsii* growing in riparian zones of a region that has a very high evaporative demand. The year-round, high green leaf area is able to constantly transpire at these high evaporative demands due to the perennially moist riparian soils. In such regions annual total evaporation rates may exceed 1500 mm. This is in contrast to the indigenous vegetation, which often becomes seasonally dormant during low flow times (Dye and Jarmain, 2004).

Annual total evaporation from *A. mearnsii* growing outside of the riparian zones but covering the entire catchment is lower than that of the riparian zone *A. mearnsii* due to drought stress from dry soils during much of the year (Dye and Jarmain, 2004). In a study of comparative water use of wattle thickets and indigenous plant communities at riparian sites in the Western Cape and KwaZulu-Natal, Dye *et al.* (2001) found that in comparison to the maximum of 1500mm per annum for dense *A. mearnsii* growing in a riparian zone, indigenous grasslands and fynbos shrublands were found to have a total annual evaporation of between 600 and 850 mm. However some other dense, tall forms of indigenous riparian vegetation would have higher total evaporation rates (Dye *et al.*, 2001). After intensive catchment instrumentation studies Dye and Jarmain (2004) concluded that increases in streamflow would be greatest following removal of dense *A. mearnsii* experiencing low levels of drought stress throughout the year in a region of high evaporative demand, with replacement by seasonally dormant indigenous vegetation. However many complex and inter-related site-specific factors determine the possible gains in streamflow from *A. mearnsii* removal, such as density and distribution of trees, spatial variation in soil moistures and different types of indigenous vegetation succeeding the *A. mearnsii* (Dye *et al.*, 2001).

Prinsloo and Scott (1999) stated that it is important to realise that streamflow is only used as a measure of the effects of IAPs on a catchment. Changes in streamflow response do not measure the whole water use of the invading plants. All changes in evaporation and transpiration as well as soilwater and groundwater recharge would not be known. This illustrates the importance of the studies on transpiration rates such as those by Dye *et al*. (2001) as mentioned above.

Although *A. mearnsii* invasion may result in less annual streamflow exiting a catchment, the erosive power of the stream may increase as a result of increased stormflow. This is because surface sealing, lower infiltration rates and reduced groundcover may result in greater overland flow and stormflow during extreme rainfall events. It is during these extreme stormflow events that river courses undergo the most change (Selby, 1993).

4. STREAM HYDROGEOMORPHOLOGY AND INVASIVE ALIEN PLANTS

Hydrogeomorphology is defined as "an interdisciplinary science that focuses on the interaction and linkage of hydrological processes with landforms or earth materials and the interaction of geomorphic processes with surface and subsurface water in temporal and spatial dimensions" (Sidle and Onda, 2004:598). As a result hydrogeomorphology encompasses the study of agents that influence fluvial geomorphology, streambank stability and riparian soil erosion. Riparian vegetation plays an integral role within fluvial geomorphology, and as such invasion of the riparian zone by alien plants can act as one of these influencing agents.

4.1 Possible Effects of Invasive Alien Plants on Soil Erosion within the Riparian Zone

Soil erosion, the removal of soil by water and wind, is a natural process. However it is a process whose rate may be magnified by anthropogenic influences, resulting in 'accelerated soil erosion' (Goudie, 1994). Human interference can act as a catalyst inducing accelerated rates of erosion (Beckedahl *et al.*, 1988). Beckedahl (1998) highlighted the economic value of soil, and the potential impacts of soil erosion, especially in a developing country. Such impacts could be; loss in agricultural production, soil degradation and loss of quality, salinisation, nutrient and soil moisture depletion, changes in soil structure, losses in crop yield and economic productivity (Beckedahl, 1998). Further disadvantages of soil erosion in more hydrological terms could be reduction of stream water quality and river ecological health, increased erosive power and increased sedimentation of impoundments.

The rate of soil erosion is determined by four factors; climate, soils, topography and land use. However land use has more effect on erosion than any of the other factors (Toy *et al*., 2002). Thus it follows that a change to alien land cover could have a strong effect on erosion rates and infestation by IAPs can cause erosion to occur at an unnatural and increased rate. Severe accelerated erosion may result in degradation of the soil to an extent where the B or C horizons are exposed to the surface (Toy *et al*., 2002). A number of factors may contribute to the accelerated erosion caused by alien plant infestations. The most relevant of these are discussed below.

4.1.1 Groundcover

A number of sources have observed that dense *A. mearnsii* infestations tended to exclude other vegetation, especially groundcover (Macdonald and Jarman, 1985; Rowntree, 1991; Shirley, 1997; Esau, 2005; Holmes *et. al.*, 2005). *R. cuneifolius* and *S. mauritianum* are also known to out compete other vegetation (Wells *et al.*, 1986). The exclusion of groundcover has major hydrological implications. The absence of groundcover results in less interception of rainfall and less infiltration, which in turn causes more overland flow and increases the potential for wash and rill erosion (Rowntree, 1991). This occurs in areas where the runoff concentrates and begins to flow at erosive velocities (Selby, 1993).

A second process related to the absence of groundcover that strongly reduces infiltration and increases overland flow is surface crusting due to raindrop impact. If the canopy is patchy or high enough over ground devoid of cover, then raindrops and drip striking the bare earth dislodge small soil particles. These small particles flow into voids in the soil surface during infiltration. This eventually results in sealing off of all voids, thus excluding infiltration and causing soil surface sealing or crusting (Selby, 1993; Beckedahl, 1998; Rowntree and Wadeson, 1999; Strunk, 2003; Harden and Scruggs, 2003). This surface crust produces rapid stormflows and further inhibits the establishment and growth of vegetation.

4.1.2 Soil hydrophobicity

Soil hydrophobicity or water repellency is an abnormality in soils resulting from the coating of soil particles with hydrophobic organic substances. These substances reduce the attraction between water and the soil particles (Scott, 1994). The longer the soil is exposed to the plant litter that contains the hydrophobic substances, the more hydrophobic it becomes. Therefore the hydrophobicity is a function of the age of the vegetation stand (amongst other influencing factors). Soil heating, such as during a fire, can also increase the water repellency of soils (Scott, 1994).

Water repellency can strongly affect the hydrological behaviour of an entire catchment. Reduced infiltration resulting in increased overland flow and greater susceptibility to erosion and gullying are the result. In addition water repellent soils are inherently drier which inhibits seedling germination and survival, providing yet another factor excluding competition and groundcover re-growth. In a study ranking the effect of vegetation on water repellency, Scott (2000) found that soils under *A. mearnsii* ranged between “somewhat repellent” to “repellent”. The study tested soil repellency from a series of forestry sites across South Africa to compare water repellency under grassland, fynbos, pine, eucalypt, *A. mearnsii* and indigenous forest. Fynbos soils and grassland soils were found to be the least repellent while *A. mearnsii* recorded the second highest repellency after eucalypts (Scott, 2000). This is significant as in invasive situations *A. mearnsii* most commonly replaces grassland and fynbos in KwaZulu-Natal and the Cape respectively. During the study it was noted that water repellency was a common feature of *A. mearnsii* plantation soils in KwaZulu-Natal.

In addition Scott (1994) stated that re-vegetation after *A. mearnsii* clearing may be complicated by the persistence of water repellency in the soil. In such cases water repellency poses minimal threat until either the region is clear felled or the groundcover is completely removed. This resulted in a high risk for overland flow, reduced soil-water replenishment and increased soil erosion (Scott, 1994).

4.2 Woody Invasive Alien Plants and Streambank Stability

The riparian bank top, the strip immediately adjacent to the top of the bank (Figure 2.1), is the zone where vegetation has a direct impact on bank stability. Thus invasion of riparian zones by IAPs has the potential to directly impact on the stability of streambanks.

4.2.1 Possible effects of woody invasive alien plants on streambank stability

In a review of available literature at the time, Rowntree (1991) found important distinctions made between grassy and woody vegetation growing on streambanks and their effect on bank stability. These concepts are illustrated in Figure 4.1, where grass with its dense root mass is effective against surface scour of the banks as well as preventing shallow bank slips. In contrast woody vegetation, such as trees, lack this protective groundcover and so do not prevent scour of the bank. In addition the weight of the trees increases the bank mass and may increase chances of failure if bank undercutting is present and the tree roots do not extend deeper than the bank height. Under these circumstances a failure plane may develop resulting in a deep seated slide (Figure 4.1). However if the rooting depth extends deeper than the height of the bank then the trees have the potential to reduce the chances of mass failure (Rowntree, 1991).

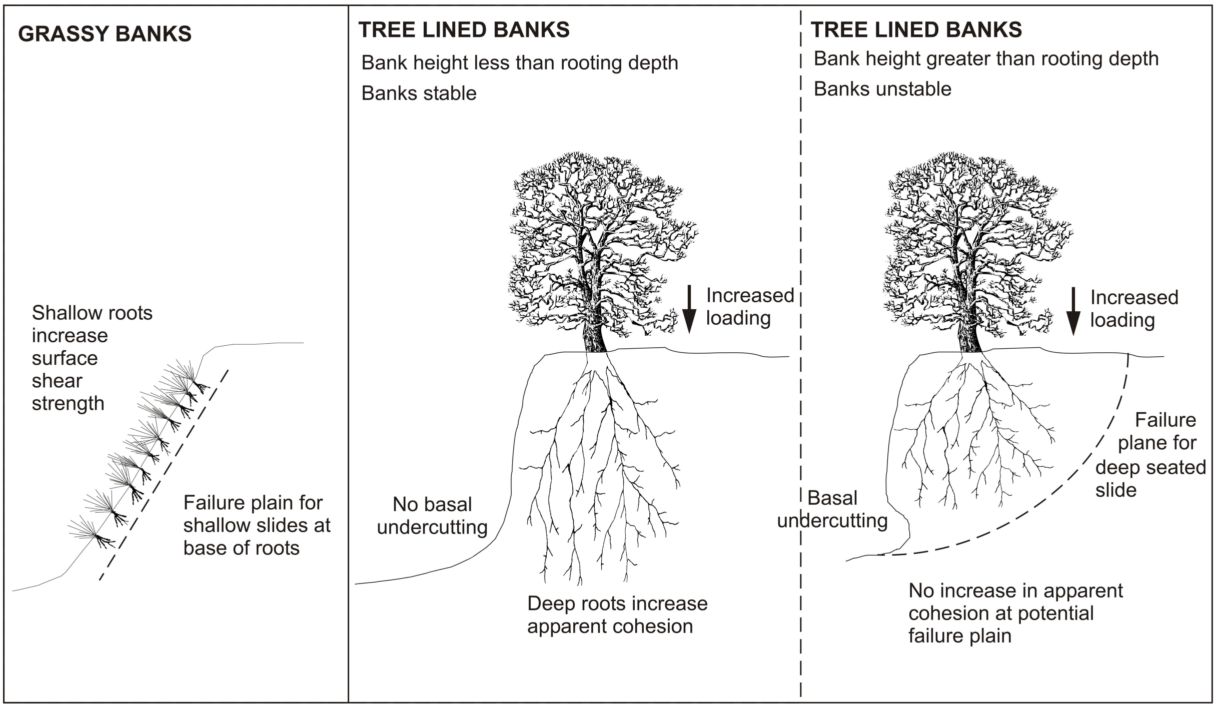

Figure 4.1 The effect of vegetation on bank stability (after Rowntree 1991)

The influence of woody invasive aliens on streambank processes is dependant on their growth form, above ground biomass, cover density and, density and extent of their roots (Rowntree, 1991). Rowntree (1991) cited numerous references quoting an association between *A. mearnsii* and accelerated bank erosion. Shallow rooting systems allow the banks to collapse, or the trees to be uprooted, during floods. *A. mearnsii* growing within floodplains is likely to increase scour during flows, due to the trees' tendency to exclude any underlying groundcover (Rowntree, 1991).

From observations of *A. mearnsii* infestations of the Mooi River near Maclear in the Eastern Cape, Rowntree (1991) noted that wherever *A. mearnsii* was present the channels were significantly deeper and narrower than the natural grassland riparian areas. It was found that he invaded reach had a lower width-depth ratio but a higher cross-section in comparison to the grassy reach. This observation supports the trends reported in the international literature reviewed by Rowntree (1991). Charlton *et al.* (1978), cited by Rowntree and Wadeson (1999), found that channels with grassy banks were on average 30% wider, while tree-lined channels were up to 30% narrower than the overall width-discharge relationship would suggest.

4.2.2 The processes of bank destabilisation

Rowntree and Wadeson (1999) classified bank condition according to three stability indicators: stable banks, active basal erosion and sub-aerial erosion. Stable banks are described as well vegetated with no sign of erosion. Active basal erosion produces vertical banks that may be undercut with signs of slumping. Sub-aerial erosion may be characteristic of sloping banks, either unvegetated or sparsely vegetated, that may have active rilling or livestock trampling (Rowntree and Wadeson, 1999).

Through a literature review Schoeman (2001) found that streambank erosion can be grouped into three broad types: sub-aerial erosion of the bank material; direct scour of the bank sediment and mass movement of the material due to gravity. Sub-aerial erosion occurs from processes that affect the surface of streambanks, either eroding them directly or rendering them more vulnerable to erosion. Direct scour occurs when the force of the flowing water exceeds the resistance force of the bank surface. The potential for scour erosion is measured by the drag exerted on a unit area of channel perimeter. This drag is the flow shear stress, and is a function of the flow depth and the slope. If the ability of the bank to resist this stress is exceeded, then particles may begin to be dislodged and entrained by the flow. If the strength of the bank aggregate is too weak to resist gravitational forces, then mass failure will occur. Once channel scour has sufficiently eroded and undercut the bank, large blocks of material may slump or collapse into the channel bed. This is most common where the bank is composed of unconsolidated material, such as in a floodplain (Figure 2.1). All three processes can actively erode at any section along a stream but at varying levels of dominance. All of the three processes will invariably act upon the stream at some stage along its length. Successful bank erosion management relies on identifying which process dominates at the site in question (Thorne, 1982; Schoeman, 2001).

Thorne (1982) found that processes of erosion acting on river banks fall into two major categories; fluvial entrainment, and sub-aerial weakening and weathering. Fluvial entrainment may cause material to be eroded directly from the bank and transported downstream, or it may cause gravitational mass failure by undercutting and over-steepening of the bank.

Sub-aerial processes can include: livestock trampling, rain splash, needle ice formation, desiccation leading to cracking and ped dislocation, damming by large woody debris or any process that destroys or weakens vegetative cover. The rate of mass failure is dependant on: the slope and geometry of the bank, the relationship of the forces acting on the bank, the physical properties of the bank material, the hydrostatic pressure and the density and nature of the overlying vegetation. Thorne (1990) stated that bank erosion usually occurs through a combination of the direct erosion of bank material by the action of water flows, and mass failure under gravity. This is followed by basal clean-out of the disturbed material.

4.2.3 Assessing streambank instability

In the past, methods of measuring bank erosion have tended to concentrate on historical sources, such as botanical (Schoeman, 2001) or sedimentological evidence (Lawler, 1993; cited by Schoeman, 2001). However, research has since developed field methods to actively monitor bank erosion. Some of these methods are: planimetric surveys, repeated cross-profiling, repeated terrestrial photogrammetric surveys and erosion pins (Schoeman, 2001).

Bank stability assessment can require more quantitative information, such as the soil properties of cohesion and friction angle, or the weight of the bank material. Many of the soil properties that determine bank stability will change with changing moisture content. An increasingly wet slope decreases the inter-particle friction of the slope, thus decreasing its stability (Dolgoff, 1996). Thus the worst-case scenario should be accounted for when assessing instability. Bank stability charts can be used to determine the stability of a bank to a high degree of accuracy. This is done through establishing a critical bank height by charting relationships between factors such as the bank slope, moisture conditions and the cohesive properties of the materials (Schoeman, 2001).

4.2.4 Rehabilitation of streambank stability

Riparian systems have a long history of abuse and mismanagement at the hands of humans. Floodplains and wetlands have been exploited for agriculture as a result of their moist, fertile soils. River channels have been modified, canalised, impounded or redirected to: alleviate floods, drain lands, store water, make way for urban development or for navigation by boat (Goudie, 1994). In the past decades environmentalists and engineers concluded that many of these alterations have resulted in unforeseen detrimental effects and that they are not ultimately sustainable. As a result there is a movement to restore or rehabilitate river systems, back to a state where they are more at harmony with the surrounding environment and are able to perform more of their essential functions. The removal of IAPs without appropriate ecosystem repair, such as bank re-stabilisation or indigenous vegetation re-establishment, can result in the riparian system not being able to resume these essential functions, and result in further degradation of the region. Thus adequate follow-up through ecosystem restoration is usually required to varying degrees at most heavily infested sites.

4.2.4.1 Restoration versus rehabilitation

Restoration can be described as the full structural and functional return of a river to a pre-disturbance state (Jensen, 1998). In contrast rehabilitation entails regaining an acceptable amount of function of the river or riparian system after disturbance has occurred. Thus the distinction between the two is that restoration implies a complete return to original condition while rehabilitation strives toward the establishment of a geomorphological and hydrological landscape that can effectively support the natural ecosystem and any other requirements of society (Brierley and Fryirs, 2005; Jensen, 1998). River restoration and river rehabilitation involves understanding of the relationships between animals, plants, water and soils and the key components required by a system. An understanding is required on which components of the system will naturally return, re-generate or stabilise versus those that require intervention, re-introduction and establishment (Jensen, 1998). Thus input from specialists in all of these fields is required for a rehabilitation project to be successful.

4.2.4.2 Approaches to bank stabilisation

The simplest method of streambank rehabilitation is to temporarily restabilise the streambanks and halt the accelerated erosion, allowing the riparian vegetation to re-establish itself and resume its role of consolidating the bank material. Thereafter the stream may stabilise and return to equilibrium in erosion and meander form. However if the river has undergone extensive disturbance, or is in imminent danger of causing loss of life or damage to infrastructure, then greater intervention will be required.

An essential pre-requisite for bank stability is bed stability. A rapidly degrading bed will cause scour at the toe of bank slopes and thus bank steepening. Rapid channel widening and bank instability will occur once the bank slopes reach their critical threshold of steepness, determined by factors which include (but are not limited to) soil type, particle size, moisture content, cohesive forces between soil particles and the weight upon the slope. Under these circumstances measures should be taken to reduce the energy gradient of the reach (Schoeman, 2001).

The applicability of a certain method or type of structure used to rehabilitate streams is dependant on many local factors due to the complexity of riparian systems. Each case needs to be investigated as to whether the method required needs to restore stability to the site or whether they merely need to provide erosion protection. In the past, purely human made materials were used to rehabilitate streambanks. Recently there is a shift toward combining these structures with natural materials. Natural materials could be dead or living plants or plant fibres woven into mats. The natural materials have the advantage that they are biodegradable and they integrate into the natural system in many ways. They attract biological life and so are not sterile structures. Natural materials that attract biological activity will accumulate nutrients and sediments, allowing plants to establish themselves more easily and aquatic life to begin regenerating. In addition structures made from artificial materials may obstruct natural flowpaths and feedbacks. For example concrete lined channels do not allow groundwater or upslope soilwater to drain into the river or contribute to low flows during dry months (Maccaferri, 2007; Gilli, 2005).

Another important consideration is the design life of the structure. Some rehabilitation structures may need only last a couple of seasons until the riparian vegetation has re-established itself. Such structures are usually built out of biodegradable materials. In other cases exotic, but not alien invasive, vegetation may be used if it can more effectively stabilise the bank and soil structure until the slower growing indigenous vegetation takes over. In other applications gabion type wire and stone structures, which can be covered in vegetation, need to keep their structural strength for decades, as the structure is pivotal in maintaining stability at the site (Gilli, 2005).

To be truly ecologically integrated the bank rehabilitation needs to account for the physical processes that include erosion and deposition associated with the lateral migration of the stream channel. Thus the rehabilitation technique would have to be selected to accommodate the dominant erosion process, such as subaerial erosion, scour or slumping. A dominance of subaerial erosion would suggest a stable bank that needs to be protected from surface erosion. Scour erosion could consist of a stable bank that has the potential to become unstable once the toe has been undercut and the bank has been over steepened. The presence of slumping would suggest that the bank is already unstable and would require anchoring as a key part of the rehabilitation process. However, the dominant erosion process is by no means the only factor controlling the stability of the bank. A bank that is merely undergoing erosion of the surface may be rendered unstable by many other factors. Dolgoff (1996), Schoeman (2001) and Rowntree (1991) identified the following factors which may render banks unstable;

- the slope gradient being near the angle of repose of the material,
- increased moisture raising the pore water pressure and thus reducing inter-particle friction,
- the presence of a bedding plane or other unconformity parallel to the shear stress of the slope, or
- increased weight placed upon the slope.

From case study examples, Holmes *et. al.* (2005) outline strategic interventions required for restoration of riparian zones within mountain streams of South Africa's summer rainfall areas;

- clear local and adjacent alien stands,
- clear aliens in the broader catchment area and maintain follow-up control,
- phase out all high-water using land-uses with marginal economic benefits,
- promote erosion of sediments under alien trees by burning alien slash in zones of accumulation,
- clear local and adjacent alien stands; kill larger trees standing,
- sow indigenous grasses once alien cover has been significantly reduced,
- establish nodes of key grassland riparian species using cuttings, or other suitable, methods, to act as sources for future propagule dissemination,
- protect any native species recruits and maintain follow-up control of alien recruits,
- control alien species in the broader catchment area and introduce biological control agents where not yet present.

4.3 The Effects of Woody Invasive Alien Plants on Stream and Channel Form

In the sections above we saw that riparian vegetation has a strong role to play in maintaining riparian bank stability, with the effect that invasion by woody IAPs is likely to destabilise riparian banks (Section 4.2), decrease resistance to erosion (Section 4.1) and modify the rate of runoff (Section 3.4). All of these three factors, namely vegetation, upslope resistance to erosion and rate of runoff (Gordon *et al*., 1992), affect stream hydrogeomorphology. Stream channels undergo constant change, however in stable channels this change can be very slow. Abrupt changes in land cover may destabilise stream channels and initiate channel erosion. Such unnaturally abrupt changes in stream form may produce large sediment loads resulting in deterioration of stream quality (Toy *et al*., 2002). Channel features, including grade and meander form, adjust to accommodate the flow and sediment load delivered to the channels from upstream. Therefore changes in land use, that modify runoff rates and sediment delivery, produce changes in the stream channels (Toy *et al*., 2002).

Riparian vegetation and hydrogeomorphological processes and landforms are intimately linked. Woody vegetation especially, may strongly affect rates of erosion and deposition (Hupp and Osterkamp, 1996; Rowntree, 1991). Abernathy and Rutherford (1998) found that vegetation plays different roles in influencing stream morphology as channel scale changes downstream. In addition the effect of vegetation will differ across regions, depending on climate, soils, topography and stratigraphy (Abernathy and Rutherford, 1998).

In bedrock channels, characterised by the absence of alluvial sediments, channel morphology is primarily determined by geologic controls and the long term erosional history of the channel. In alluvial channels stream form is related to discharge patterns and sediment supply, erosion and deposition dynamics (Brierley and Fryirs, 2005; Rowntree, 2000; Wadeson, 1994). The degree of erosion or deposition depends on the balance between the erosive force of the flow and the erodibility of the substrate, both of which can be affected by vegetation (Rowntree, 1991). As a result of this balance, alluvial channels are more susceptible to rapid change as a result of disturbances, such as a change in riparian and streambank vegetation cover.

At many *A. mearnsii* infestation sites the influence of large woody debris plays a significant role in altering stream geomorphology (Rowntree, 1991; Shirley, 1997). The influence of woody debris is strongest in narrow, steep headwater streams that contain rocks and boulders (Rowntree, 1991; Piegay *et al.*, 1999). Debris dams within headwater streams may also contribute to channel widening (Rowntree, 1991). In addition, large woody debris congesting the main channel may lead to water flow diversions, causing artificial braiding, and may reduce interconnectivity between main and sub channels as well as cause erosion (Tabacche *et* *al.,* 2000). In terms of the vegetation the effect of large woody debris on streamflows is a function of tree age, height and stand density. This is as a result of the higher woody biomass present as well as the presence of higher numbers of larger trunks and branches (Rowntree, 1991; Bosch *et al.,* 1994; Shirley, 1997; Piegay *et al.,* 1999).

Large woody debris has a number of effects on stream ecology and hydrogeomorphology as well as the flow regime of the river. Woody debris changes the water quality, introducing more organic matter, which has implications for aquatic life. A damming effect creates artificial pools and temporary base levels (Rowntree, 1991). Thus the natural downstream cycles of aggradation and degradation are upset resulting in the natural riffle and pool sequences being disturbed. In addition flow speeds can be significantly altered. Arguably the most damaging consequence is the increased danger of riverbank overtopping and extensive flooding after extreme rainfall events (Rowntree, 1991; Bosch *et al.*, 1994). This is due to the natural flow regime being altered by the many debris dams obstructing flow. Natural flood attenuation processes and even floodplains are rendered insufficient to limit the damage. Woody debris can accumulate against tree stems and trunks within the floodplain region of the river. Extensive damage can be caused to riverbanks and bridges during floods (Bosch *et al.,* 1994).

Rowntree (1991) cited several references describing an increase in channel width above debris dams in comparison to natural channels, which were more incised. In addition significant quantities of coarse sediment can be trapped at these steps in the channel profile. These influences could significantly change the geomorphology and form of stream channels.

Rowntree (1991) referred to a field study of the Mooi River near Maclear (Rowntree, 1990), which noted that wherever *A. mearnsii* had invaded, the channels were significantly deeper and narrower than where the banks supported a natural grass cover. At this section the Mooi River flows through a lowland area and forms a high order river. Through the findings of other researchers Rowntree (1991) described that the converse seems to apply at low order, steeper, headwater streams, where invasion could lead to local channel widening with associated lateral erosion of the channel banks.

5. RIVER SURVEYING

Rivers and their riparian systems are extremely complex and dynamic. In addition they carve their way through a variety of different neighbouring ecosystems and landforms on their way to the sea. Riparian systems can be seen as long open ecosystems linked longitudinally, but also linked laterally and vertically by hydrologic, geomorphic and biological processes and systems. River ecosystems intimately interact and connect with their surrounding landforms. (Tabacchi *et al.*, 1998). As a result stream and riparian surveys can become extremely complex.

5.1 Theory and Purpose of River Surveying

When classifying and analysing fluvial systems and riparian landscapes, scientists must correctly identify both their characteristic forms and features, and the fluvial processes responsible for producing and maintaining them (Thorne, 1998). Thorne (1998) stated that a disciplined and methodical approach is essential and that an effective stream survey method should;

- supply a methodological basis for field studies of channel form and process,
- present a format for the collection of qualitative information and quantitative data on the fluvial system,
- provide a vehicle for progressive morphological studies starting with a broad catchment baseline study, through an audit of the fluvial system, to a detailed investigation of geomorphological forms and processes in critical reaches, and
- supply the data and input information to support techniques of geomorphological classification, analysis and prediction necessary to support sustainable river engineering, conservation and management (Thorne, 1998).

Whole textbooks have been written on the geomorphological processes operating within riparian systems, similarly within the fields of hydrology and ecology. A stream survey needs to encompass all three disciplines without being overly complex. Some variables are more valuable to ecologists, while others are more valuable to geomorphologists or hydrologists. As a result the survey method and data gathered should be tailored so as to gather all the relevant information required for the study. It is important to be comprehensive so that additional site visits are not necessary at a later stage to gather information that was previously not thought relevant. If the stream survey forms part of a national river assessment survey to be input into a national database, then the gathering of data encompassing all fields of study is most useful.

5.2 Methods of River Survey and Classification

Selected methods of stream survey were reviewed to explore their capabilities and potential applicability in contributing toward the field research aims of the project, as expanded upon in Chapter 6. A brief summary of each method follows.

5.2.1 River Habitat Survey

The River Habitat Survey (RHS) (Appendix 2) was developed by the National Rivers Authority and the Environment Agency of the United Kingdom in accordance with the goals set out in 1992 by the European Water Framework Directive. The RHS has been designed, tested and improved through extensive use and testing on rivers in the United Kingdom since 1994, with a revised version released in 2003. The system provides a standard method for assessing the overall physical character and habitat quality of rivers. The field survey requires the user to recognise vegetation types and have an understanding of basic geomorphological principles and processes. Specialist geomorphological or botanical expertise is thus not required to perform the survey (Environment Agency, 2003).

The RHS is intended to be performed along a 500m length of river channel. Ten observation spot check points are spaced equidistantly along the 500m length. While walking along the reach the surveyor observes valley form and surrounding land use to be captured onto the survey sheet. The backbone of an observational method such as the RHS is confidence in the survey data. This requires consistent recording of features by competent surveyors, well-trained in the methods of the RHS. The completed forms are entered into an RHS database, which then builds an information database on all surveyed rivers in the UK. The RHS survey form is four pages in length, with two additional pages providing a key (Appendix 2). Surveyors are required to note the presence, absence, and in some cases the number or extent of certain features. Two hundred separate field observations on habitat features and structural modification to the channel are recorded on the form (Environment Agency, 2003).

Four basic types of records constitute the form;

- counting the number of specific features within the entire 500m reach,
- ticking boxes to indicate whether a feature is present, absent or extensive,
- entering a two letter acronym, from the key, for features at each of the ten spot-check sites, and
- taking physical measurements of the channel such as height, width and depth.

The data gathered from RHS surveys is input into an extensive national database of river habitat health for the UK. The computer database is then able to perform rapid analysis of the data and includes outputs for expressing habitat quality and artificial channel modification.

Surveyors attend a compulsory training and accreditation programme before their survey data will be accepted by the Environment Agency for input into the database. Photographs form an essential component to the River Habitat Survey to aid in the interpretation of data and as a record of the site for future reference. Channel modifications must be noted and photographed as well as any major structures within the channel. Any unusual features that the surveyor is unsure of are photographed and accompanied with appropriate notes (Environment Agency, 2003).

5.2.2 Hydraulic biotopes

Rowntree and Wadeson (1999) introduce the concept of a hydraulic biotope for use in the classification of South African Rivers. In ecological terms a biotope is considered the abiotic environment of a community, as opposed to a habitat which is the abiotic environment of a species. A hydraulic biotope is used for the description of ecologically significant instream flow environments. This area within the stream must be characterised by distinct flow conditions and must have special ecological significance for the distribution of aquatic biota. A hydraulic biotope may be defined as a spatially distinct in-stream flow environment characterised by specific hydraulic and substrate attributes (Rowntree and Wadeson, 1999). A description of ecologically significant hydraulic biotopes common within South African rivers is given by Rowntree and Wadeson (1999) in Table 5.1.

Table 5.1 Ecologically significant hydraulic biotopes common within South African rivers (after Rowntree and Wadeson, 1999)

HYDRAULIC BIOTOPE	DEFINITION
POOL	This feature has through flow at a very slow velocity. The combination of velocity and depth allows depositions of fine particulate matter over substrate of all sizes
RIFFLES	Flow over cobbles, gravel and boulders and have a shallow depth relative to bed material size. Consist of rapid, super-critical flow and indicate a distinct gradient change of the water surface. At increased discharge becomes a run.
RUN	Represented by tranquil flow, no broken water on the surface, with any substrate. No obvious stream bed gradient change. Runs have a higher depth to substrate size ratio than for riffles.
BACKWATER	A hydraulically detached feature where there is no through flow of water. Movement occurs through a single entrance/exit with low or no velocity. Are of variable depth, all substrate types, generaly covered in fine silt and sand.
CASCADES	Cascades consist of free falling water in step like fashion over bedrock.
WATERFALLS	Waterfalls are similar to cascades but higher. There is more free fall of water relative to horizontal movement. Height is the most important defining variable
GLIDE	This is a shallow, unconstricted, smooth flow over bedrock. Bed roughness is relatively low. It becomes a run over bedrock at higher flows.
CHUTE	This consists of a narrow constricted flow over bedrock. Depth produces smooth flow at the surface. If flow becomes super-critical, the feature becomes a rapid.
RAPID	This feature is similar to a glide but has broken water. It occurs over bedrock or boulders. The critical feature is velocity, which must be high, together with the form ratios of width to depth, which must be low.

5.2.3 Geomorphological Driver Assessment Index

The Geomorphological Driver Assessment Index (GAI) was developed to assist with establishing geomorphological reference conditions with regards to South Africa’s Resource Directed Measures and the River Health Programme (RHP). The index, using a rule-based model, is used to derive the “Geomorphological Ecological Category” of a river reach. The GAI takes account of weighted ratings of system connectivity, reach sediment balance, channel perimeter resistance and morphological change to give an indication of the “Geomorphological Ecological Category” of the study reach. With respect to the RHP, Kleynhans *et.al.* (2005) stated that the GAI was not developed as a monitoring tool, but could be used to identify the impact of major system changes over the time scale of the monitoring programme.

5.2.4 Riparian Vegetation Response Assessment Index

The Riparian Vegetation Response Assessment Index (VEGRAI) was developed as a rapid approach tool for the assessment of changes in riparian vegetation in South African rivers. VEGRAI makes use of a spreadsheet model to apply different ratings obtained in the field through field data sheets, to a range of metrics and metric groups (marginal, lower and upper riparian vegetation zones). The metrics describe current and reference states of the riparian vegetation and then compare differences between the two states to give an indication of vegetation response to an impact regime. In addition the assessment provides an indication of the possible causes of riparian vegetation degradation. Two levels of assessment were developed for widespread use; a Level 3 assessment was developed for application in the RHP and for rapid Ecological Reserve determination, while a Level 4 assessment was developed for intermediate and comprehensive ecological reserve determinations. The method takes account of woody and non-woody components and while it accounts separately for the different vegetation zones, it also provides an overall index value for the riparian vegetation zone as a unit (Kleynhans *et. al.*, 2007).

5.2.5 Index of Habitat Integrity

The Index of Habitat Integrity (IHI) was developed as a tool which can be utilised to assess the habitat integrity of riparian systems, ultimately assigning the study reach to a habitat integrity category. The habitat being assessed is assigned to one of six habitat integrity categories, ranging from A, “unmodified natural” to F, “critically/extremely modified”. As an assessment of the present ecological state of rivers, the IHI can be utilised in reserve determinations and forms a component of the RHP. The IHI is comprised of two subcomponent integrity assessments; the Instream Habitat Integrity assessment and the Riparian Zone Habitat Integrity assessment. The instream component is based on five metric groups; hydrological modification, Physico-chemical modification, bed modification, bank modification and connectivity modification. The riparian zone component is based on three metric groups; hydrological modification, bank structure modification and riparian zone connectivity. As with the VEGRAI, all of the metric groups have different weightings, and the assessment of habitat integrity is based on an interpretation of the deviation from the reference condition (Kleynhans *et al.*, 2009).

The Geomorphological Driver Assessment Index (GAI), the Riparian Vegetation Response Assessment Index (VEGRAI) and the Index of Habitat Integrity (IHI) form components of the ECOSTATUS model. The ECOSTATUS model was developed as a rapid assessment tool to determine the integrity and ecological state of riparian habitats within South Africa.

5.2.6 South African Scoring System

The South African Scoring System version 5 (SASS5) is a rapid method of stream aquatic health assessment. The method is reliable, quick and cost-effective and has become the standard method for the rapid bioassessment of rivers in South Africa. SASS5 has been recommended for the determination of the flow requirements of rivers and for impact assessments within South Africa (Dickens and Graham, 2002). Dickens and Graham (2002) state that biomonitoring methods such as SASS may be used to;

- assess the ecological state of aquatic ecosystems,
- assess the spatial and temporal trends in ecological state,
- assess emerging problems,
- set objectives for rivers,
- assess the impacts of developments,
- predict changes in the ecosystem due to developments,
- contribute to the determination of the Ecological Reserve.

The SASS rapid bioassessment method was developed from two British approaches; principally the Biological Monitoring Working Party (BMWP) score system, but also from the River Invertebrate Prediction and Classification System (RIVPACS) (Chutter, 1998). The method of macroinvertebrate collection is based on ‘kick-sampling’ where a net is held downstream while stones in the riverbed are moved and kicked with the feet for a set period of time. The contents collected in the net are then placed in water-filled trays and the species of benthic macroinvertebrates that are present are then identified and counted. Different family groups of benthic macroinvertebrates have different susceptibilities or resistances to pollution. Thus presence or absence of different species of macroinvertebrate gives an indication as to the water quality of the river. Benthic macroinvertebrates are valuable organisms for water quality assessments as they are visible to the naked eye, are easily identifiable, have a rapid life cycle and tend to remain in a single area throughout their short life (Dickens and Graham, 2002). Due to their rapid life cycle, macroinvertebrates give an up-to-date indication of river water quality (Chutter, 1998). Dickens and Graham (2002) found that of the various indices available to the method (others being the SASS score and Number of Taxa), the Average Score Per Taxon (ASPT) was the most consistent over all biotopes with the lowest CV%.

The SASS test is designed for low or moderate flow systems and samples should not be taken during flood. Summer high flows may even produce poor results. In addition the method cannot be used in wetlands, impoundments, estuaries and other lentic habitats (very slow moving or standing water). The test works best in rivers where a full range of biotopes is present. Samples should be taken across the various biotopes and over a wide area within each biotope to ensure that the full variability is accounted for. Biotopes from which macroinvertebrates are collected include stones in current, stones out of current, marginal or aquatic vegetation, and gravel, sand or mud biotopes (Dickens and Graham, 2002).

Vos *et al.* (2002) highlight that SASS can be used to reflect changes in physical-chemical water quality. As a result the SASS method could potentially be used to assess the impacts of indigenous or exotic vegetation, growing within the riparian zone, on water quality. Although the method is fast and convenient, care must be taken in the interpretation of results. Seasonal variation must be accounted for in the interpretation of results as well as information on the habitats sampled, the proximity of dams, weirs and bridges and the channel characteristics. In terms of water quality assessment the method is better used to illustrate trends in water quality change over time at the specific site. However if performed correctly the test is sensitive to all types of water quality change (Chutter, 1998).

5.3 Methods of River Survey to be Integrated into the Field Study

The UK RHS was utilised by the author to develop the Modified River Habitat Survey MRHS for application in the fieldwork component of this dissertation. The development of the MRHS is discussed in Chapter 6.4.

The hydraulic biotopes outlined by Rowntree and Wadeson (1999) were integrated into the MRHS spot-check transect key (Table 6.1) to tailor the survey to the ecologically significant hydraulic biotopes common within South African rivers. Concepts and terms relating to hydraulic flow biotopes extracted from King and Schael (2001) and Rowntree and Wadeson (1999) were utilised by the author in the development of a morphological mapping methodology which was applied during the fieldwork. The integration of the hydraulic biotopes into the field methods is discussed in Sections 6.2.1 and 6.2.2.

The GAI, VEGRAI and IHI methods were not readily available for integration into the fieldwork section of this study which began in 2005, but were reviewed to include the latest developments within the field. It was thought that aspects of the methods may be applicable to the analysis of the data gathered by the MRHS, however there was insufficient data overlap.

The SASS5 rapid bioassessment method was earmarked for integration into the field methodology to test the potential impacts of IAPs on water quality. The method may pick up impacts on aquatic invertebrates associated with changes in water temperature, the development of pools associated with woody debris and changes in water chemistry which may be associated with wattle debris and tannins. Graham (2009) confirmed that the SASS5 test may pick up such impacts of IAPs on water quality, but that the standard method is not specifically tailored to this. The method is better applied to illustrating changes in water quality over time at a specific site. Due to the nature of the research sites, with different flow regimes, flow volumes and greatly different riparian zone vegetation composition the SASS5 aquatic sampling would more likely pick up the biophysical variations across the sites rather than the specific impacts of the IAPs on aquatic invertebrates. The method would be more applicable to monitor trends in water quality change over time at a specific site in response to a change in treatment, such as clearing of the IAPs. Recognising the research aims of this dissertation, which focus on IAP impacts on streambank stability and channel form, it was decided that utilisation of SASS5 would not facilitate the key focus of this study.

The integration of the RHS and hydraulic biotopes into the fieldwork methodology of this study is discussed in Section 6.4.

6. FIELDWORK METHODOLOGY

The fieldwork component of this dissertation aimed to assess the affects that woody Invasive Alien Plants (IAPs) have on bank stability and meso-scale channel form within the riparian zone. Through the MRHS the fieldwork will also give an indication of the impacts IAPs may have on indigenous riparian vegetation and soil erosion within the riparian zone.

6.1 Field Site Identification and Locality

The methodology applied in field site selection was to identify three study sites at each of the two locations; a stream reach that was heavily infested with IAPs, a stream reach cleared of IAPs, and a stream reach which was in a predominantly natural condition. These sets of three sites were to be repeated at a second location for comparison. Two fieldwork locations were identified in two different regions of KwaZulu-Natal, South Africa (Figure 6.1).

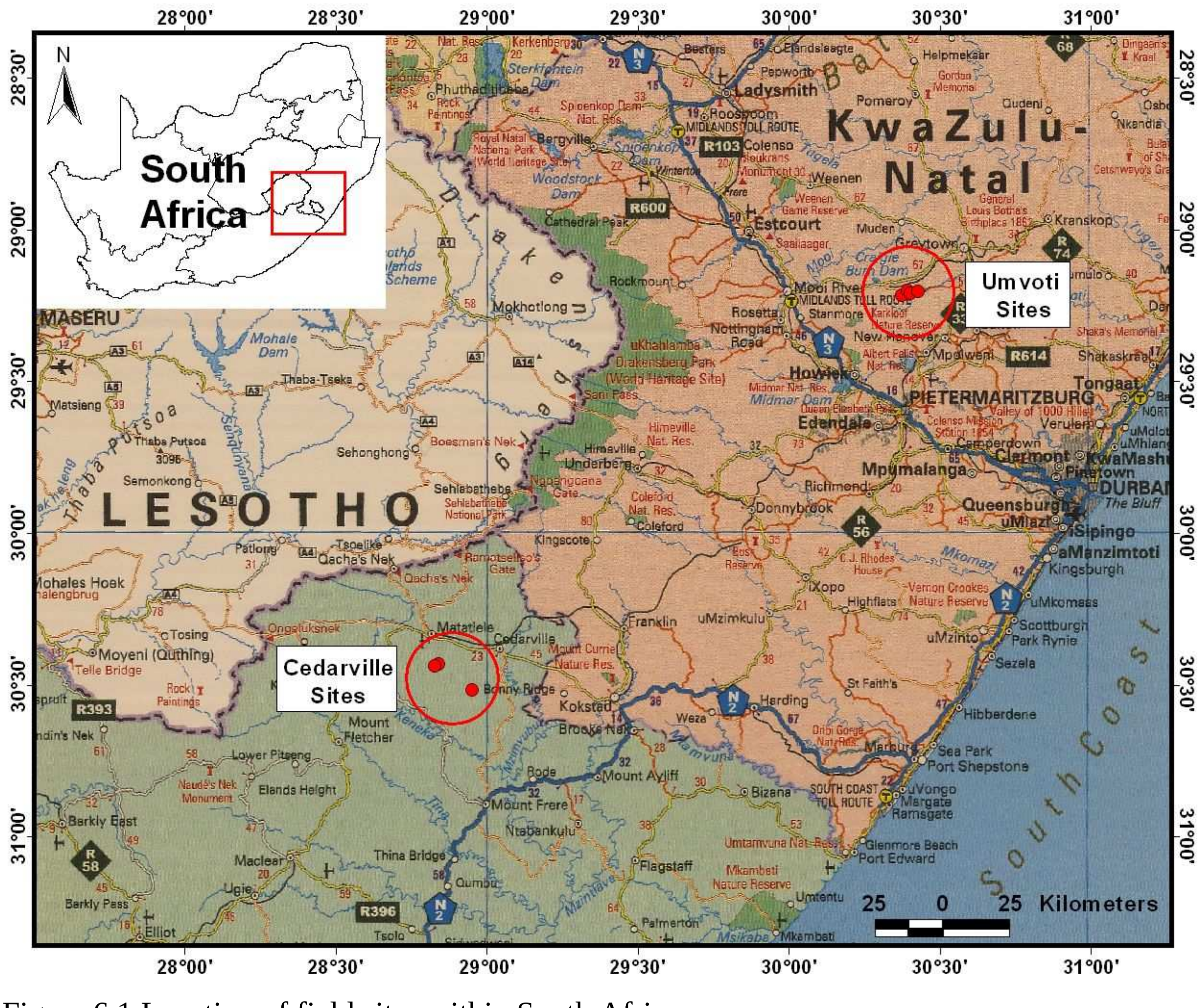

Figure 6.1 Location of field sites within South Africa

Due to access restrictions on private farm land, the vast land area with a diversity of habitats available under a single commercial forestry organisation, and existing research relationships with a commercial forestry organisation, the Umvoti sites were prospected on commercial forestry land. The Cedarville sites were located on private farmland familiar to the author, and where research had been undertaken previously.

The primary site was located 25 km's South West of Greytown, within the headwaters of the Umvoti River catchment, upstream of Umvoti Vlei (Figure 6.2). The secondary site was located near Cedarville within the headwaters of the Mvenyane River system, a tributary of the Mzimvubu River (Figure 6.3). At both study areas *A .mearnsii* was the dominant woody IAP within the riparian zones.

6.1.1 Umvoti field sites

The Umvoti study area comprised of four sites;

- Site U1 - an IAP infested site where the riparian zone was infested with Invasive Alien Plants, predominantly *A. mearnsii*,
- Site U2 - a natural site where the riparian zone contained natural vegetation,
- Site U3 - a cleared site where the riparian zone has a history of invasion with just a few species of IAP remaining,
- Site U4 - a cleared site where the riparian zone has a history of invasion with the stumps of large woody IAPs being present (Figure 6.2).

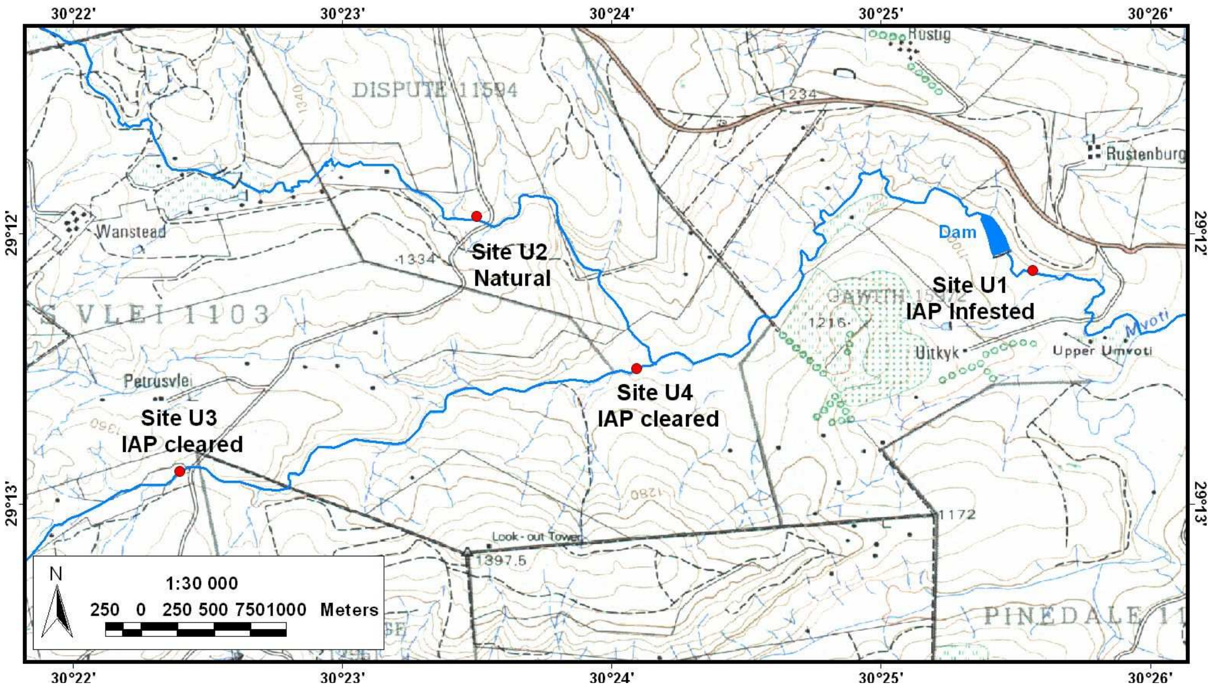

Figure 6.2 Relative locations of the Umvoti field sites

6.1.2 Cedarville field sites

The Cedarville study area comprised of three sites;

- Site C1 - an IAP infested site,
- Site C2 - a predominantly natural site, with scattered IAPs present,
- Site C3 - a site with a lower density of IAP infestation than Site C1 (Figure 6.3).

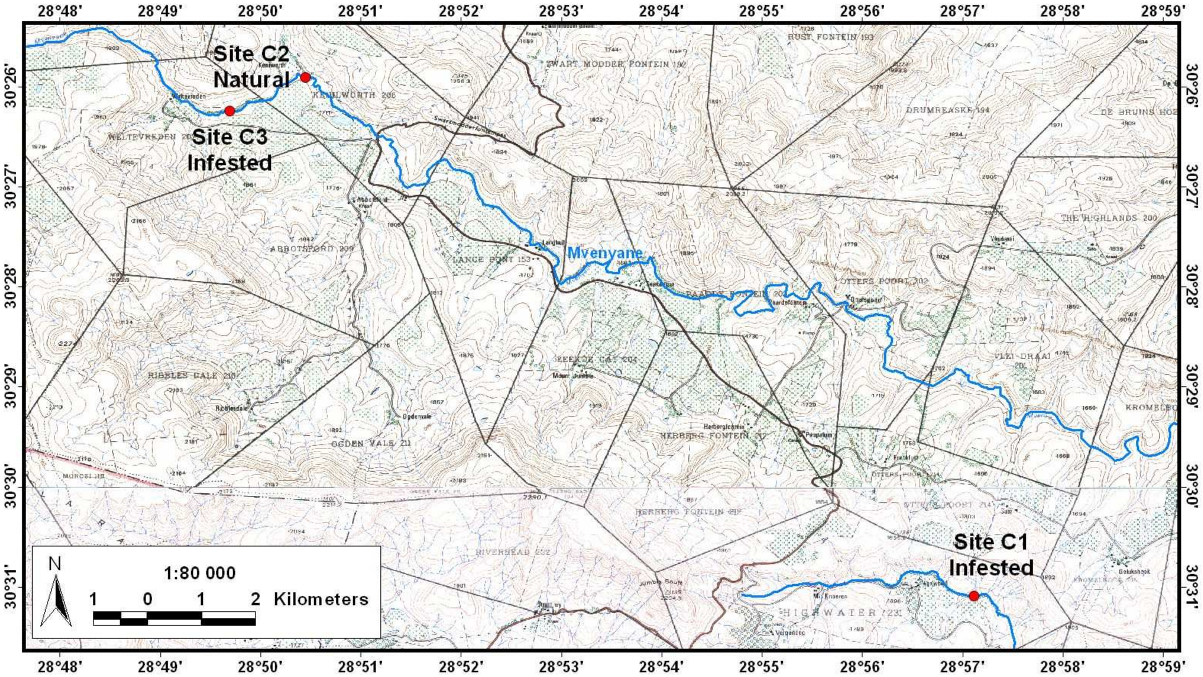

Figure 6.3 Relative locations of the Cedarville field sites

6.2 Site Biophysical Descriptions and Observations

The main focus of the fieldwork fell on the Mvoti study area, where the highest number of assessments was undertaken (Table 6.1).

Table 6.1 Field sites and applied field assessments

Site area	Site name	Description	MRHS	Photographic analysis	Cross profiles	Morphological maps
Umvoti	U1	IAP infested	X	X	X	X
Umvoti	U2	Natural	X	X	X	X
Umvoti	U3	IAP cleared	X	X	-	X
Umvoti	U4	IAP cleared	X	-	-	-
Cedarville	C1	IAP infested	X	X	X	-
Cedarville	C2	Natural	X	X	X	-
Cedarville	C3	IAP infested	X	X	X	-

The Umvoti sites were located within a large forestry region, with the majority of the catchment's landuse being commercial forestry. The Cedarville sites were located within a private farming region, with the majority of the surrounding catchment being utilised for beef cattle grazing. Table 6.2 illustrates the upstream catchment area of each site, the slope of the study reach, and the stream order of each river reach performed according to the Strahler stream order method.

Table 6.2 Physical and catchment characteristics of the field sites

Site area	Site name	Description	Upstream catchment area	Slope of study reach (%)	Stream order (Strahler, 1952)
Umvoti	U1	IAP infested	28.61	2.0	5
Umvoti	U2	Natural	11.35	3.0	4
Umvoti	U3	IAP cleared	2.00	2.3	3
Umvoti	U4	IAP cleared	9.82	3.2	4
Cedarville	C1	IAP infested	12.82	3.4	4
Cedarville	C2	Natural	39.78	0.6	4
Cedarville	C3	IAP infested	29.70	1.0	4

6.2.1 Umvoti IAP infested Site U1

Figure 6.4 Umvoti IAP infested Site U1 showing IAP infested riparian zone and streamflow direction

The channel bed of Site U1 was comprised of largely unconsolidated material, but with boulders and cobble present. At the time of survey the riparian zone was densely infested with invasive wattle to the exclusion of groundcover in many sections. The valley form was asymmetrical, with a steep valley side shown in the foreground of Figure 6.4 and a flat valley side extending from the opposite bank. Old cultivated lands are present within proximity of the right bank (Figure 6.5). A large farm dam (Figure 6.2), with an earth dam wall of approximately 110m length, is located approximately 300m upstream of the 500m long study reach. The width of water within the channel at the MRHS transects of the 500m reach ranged from 1.9m to 4.3m, with the maximum water depth ranging from 0.24m to 0.98m at the time of survey. The MRHS was performed at 10 transects, but with the GPS cross-profiles only being performed at transects 1 to 6 as the left bank of transects 7-10 contained rocky cliffs in excess of 3m in height.

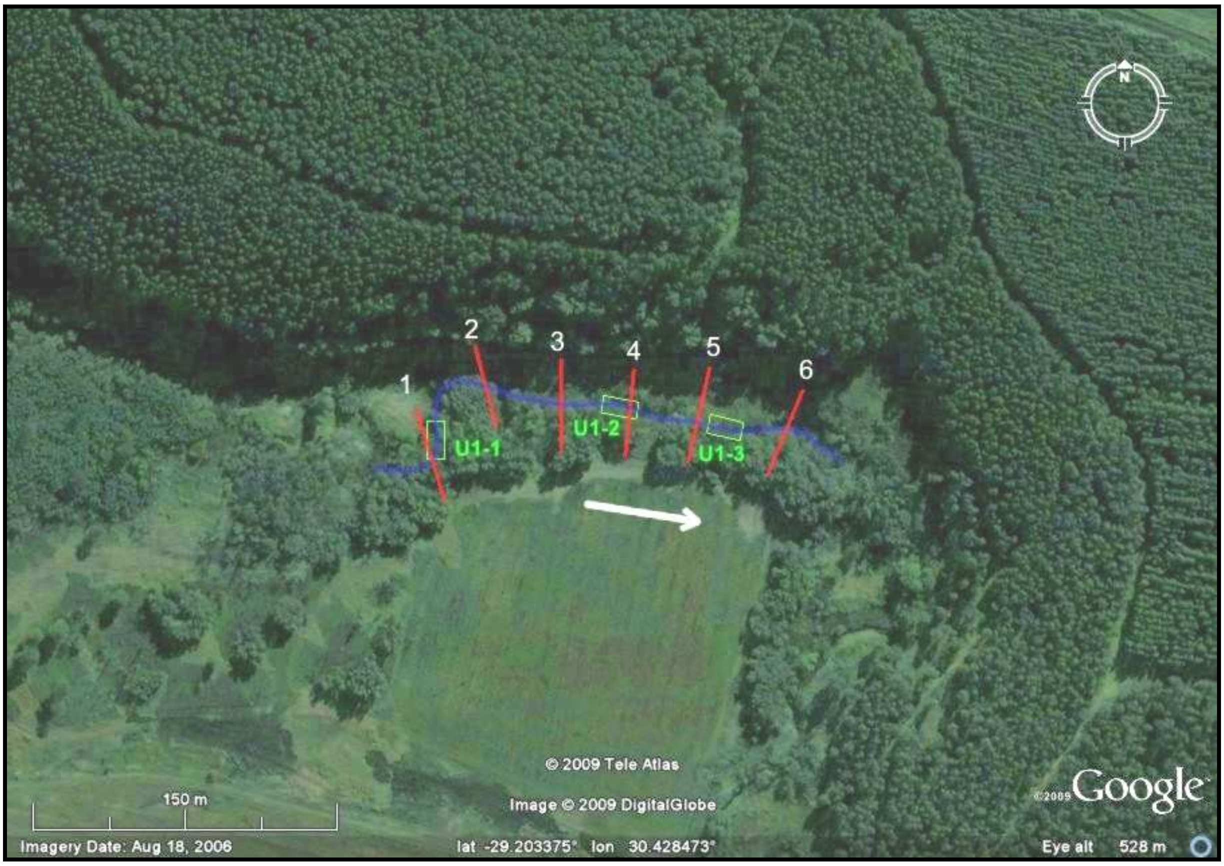

Figure 6.5 Aerial view of Site U1 study reach, MRHS/cross-profile transects 1-6 and morphological map sites U2-1 to U2-3

6.2.2 Umvoti natural Site U2

Figure 6.6 Umvoti natural Site U2 showing absence of IAPs

The Umvoti natural Site U2, was the most undisturbed section of river which could be found in the region, with only a few scattered individuals of invasive *Acacia* species found within the riparian zone at the time of survey. The riparian zone and surrounding slopes were dominated by grassland. The river is a bedrock dominated system, with the river bed comprising of bedrock for a large portion of the 500m study reach. At the foot and the head of the 500m reach (Figure 6.7) the valley form is asymmetrical, with the left bank (looking downstream) being significantly steeper in both cases. The central portion of the 500m reach, shown in the foreground of Figure 6.6, has a more symmetrical valley form. The dolerite intrusions associated with the bedrock culminate in a waterfall of greater than 5m height approximately 650m downstream of the site. The width of water within the channel at the MRHS transects of the 500m reach ranged from 1m to 3m, with the maximum water depth ranging from 0.15m to 1.1m at the time of survey.

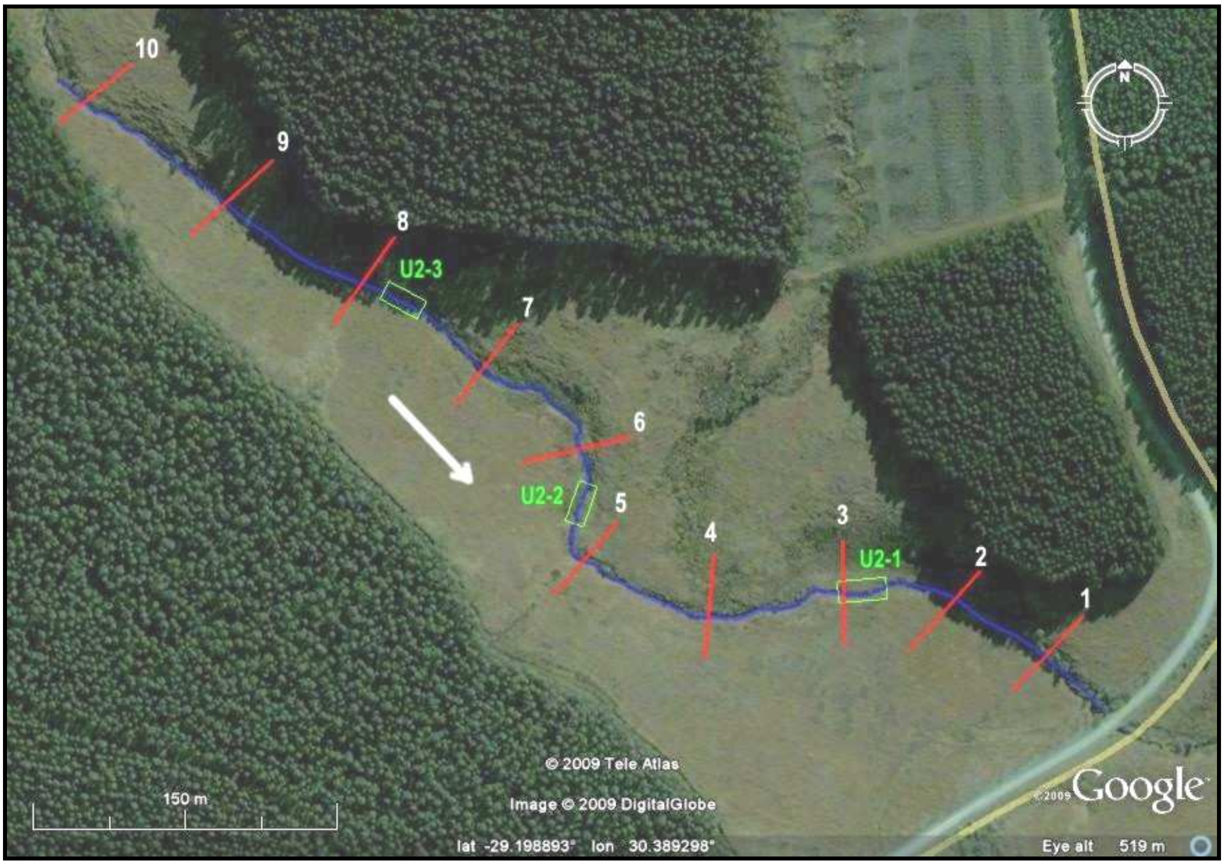

Figure 6.7 Aerial view of Site U2 study reach, MRHS/cross-profile transects 1-10 and morphological map sites U2-1 to U2-3

6.2.3 Umvoti IAP cleared Site U3

Figure 6.8 Umvoti IAP cleared Site U3 showing absence of woody IAPs

Site U3 shows evidence of the past presence of woody IAPs in the form of stumps scattered sparsely at various points along the channel banktop. The channel form is strongly meandering, as can be seen in Figure 6.9, with an average channel depth and width of 1.2m and 3.5m respectively at the time of survey. During the winter site visit, open water was not present along the entire 500m study reach, but scattered pools were present, as were signs of water seepage from the channel sides. The meandering reflects the flat relief of the site, which formed an open valley (Figure 6.8), and was classified as a 'shallow vee' in the MRHS form. Due to the relief of the site and the absence of macro-channel banks, it is suspected that the site formerly contained a significant area of wetland habitat. This was confirmed through a soils analysis utilising an auger to extract subsurface soil samples. Greyed soils with signs of mottling were found within 500 mm of the surface, which according to the DWAF (2005) guidelines, *A Practical Field Procedure for Identification and Delineation of Wetland and Riparian areas,* indicates the presence of wetland soils displaying signs of temporary wetness.

The site may have previously been an unchanneled valley bottom wetland, which may have been intentionally drained by an artificial channel, or a channel may have developed following erosion. Upstream of the 500m study reach the channel is straight enough to suggest parts of it may be artificial, possibly dug by historical land owners for wetland drainage purposes.

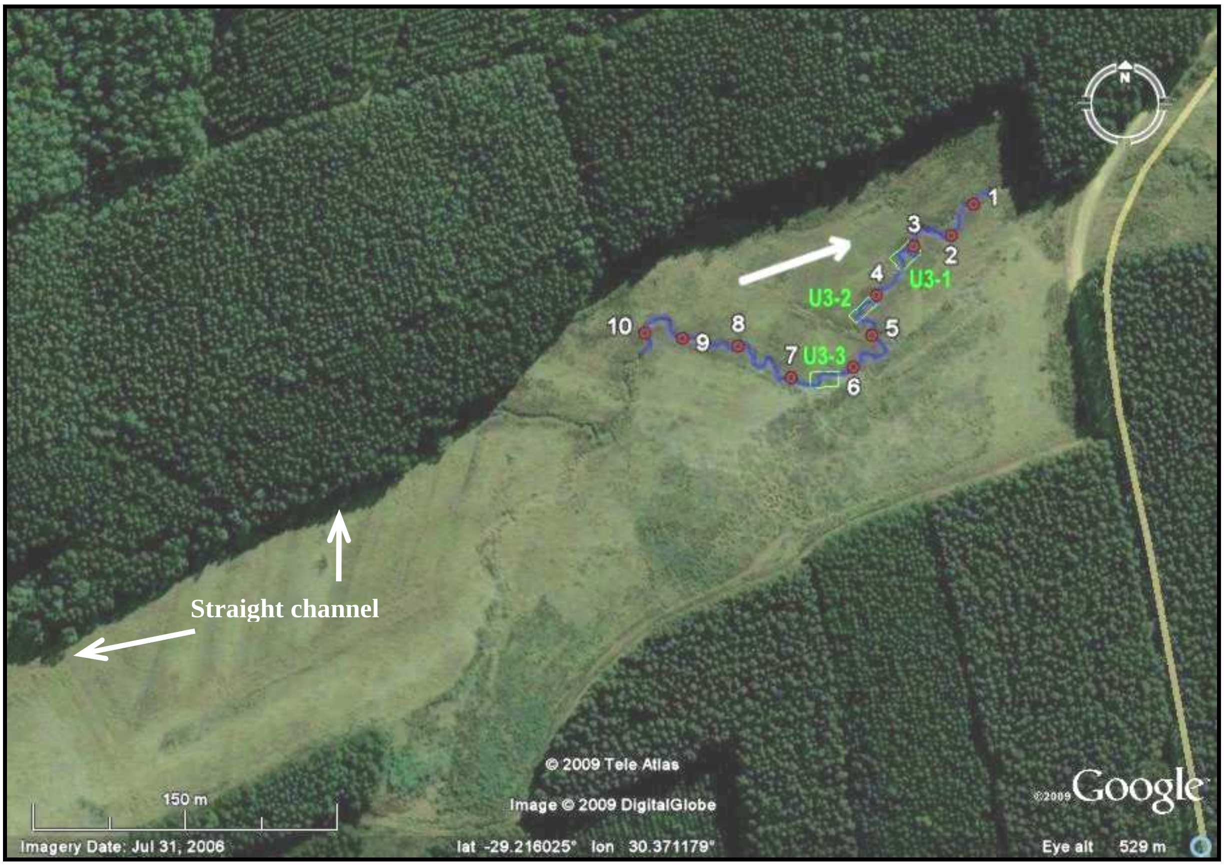

Figure 6.9 Aerial view of Site U3 study reach, MRHS/cross-profile transects 1-10 and morphological map sites U3-1 to U3-3

6.2.4 Umvoti IAP cleared Site U4

Figure 6.10 Umvoti IAP cleared Site U4 showing presence of some woody IAPs

Site U4 was classified as an IAP cleared site as the study focussed on the impact of large woody IAPs, which appeared to have been present in the near past due to the presence of invasive *Acacia* stumps. Since clearing of the large woody IAPs the site was colonised by *S. mauritianum* which had formed a closed canopy over portions of the site at the time of the fieldwork (Figure 6.10 and 6.11), but which would likely be cleared by the commercial foresters in due course through their IAP clearing follow-up schedule. Scattered individuals of invasive *Acacia* were present within the riparian zone. The stream bed consists of unconsolidated material, with the average channel depth of the study reach being 2.2m and the average width 4.6m at the time of survey. Site 4 was characterised by a concave, bowl shaped valley with a flat valley bottom.

Figure 6.11 Aerial view of Site U4 study reach and MRHS transect points

6.2.5 Cedarville IAP infested Site C1

Figure 6.12 Cedarville IAP infested Site C1 showing density of alien invasive wattle

IAP infested Site C1 comprises of a riparian zone which was heavily infested with invasive *Acacia* species of varying age (Figure 6.12 and 6.13). The invasion by the woody IAPs extends from just below the source of the Mvenyane River a few kilometres to the west of the site, and continues for many kilometres downstream to the confluence with the Mzimvubu River. The study reach is a bedrock dominated site, with the stream bed crossing bedrock at numerous sections. At the time of survey the average channel depth of the study reach was 2.4m, with the average width being 8m. The width of water within the channel ranged from 2.1m to 6.2 across the ten transects, with maximum water depths from 0.02m to 0.35m at the time of survey.

Figure 6.13 Aerial view of Site C1 study reach and MRHS/cross-profile transects 1-10

6.2.6 Cedarville natural Site C2

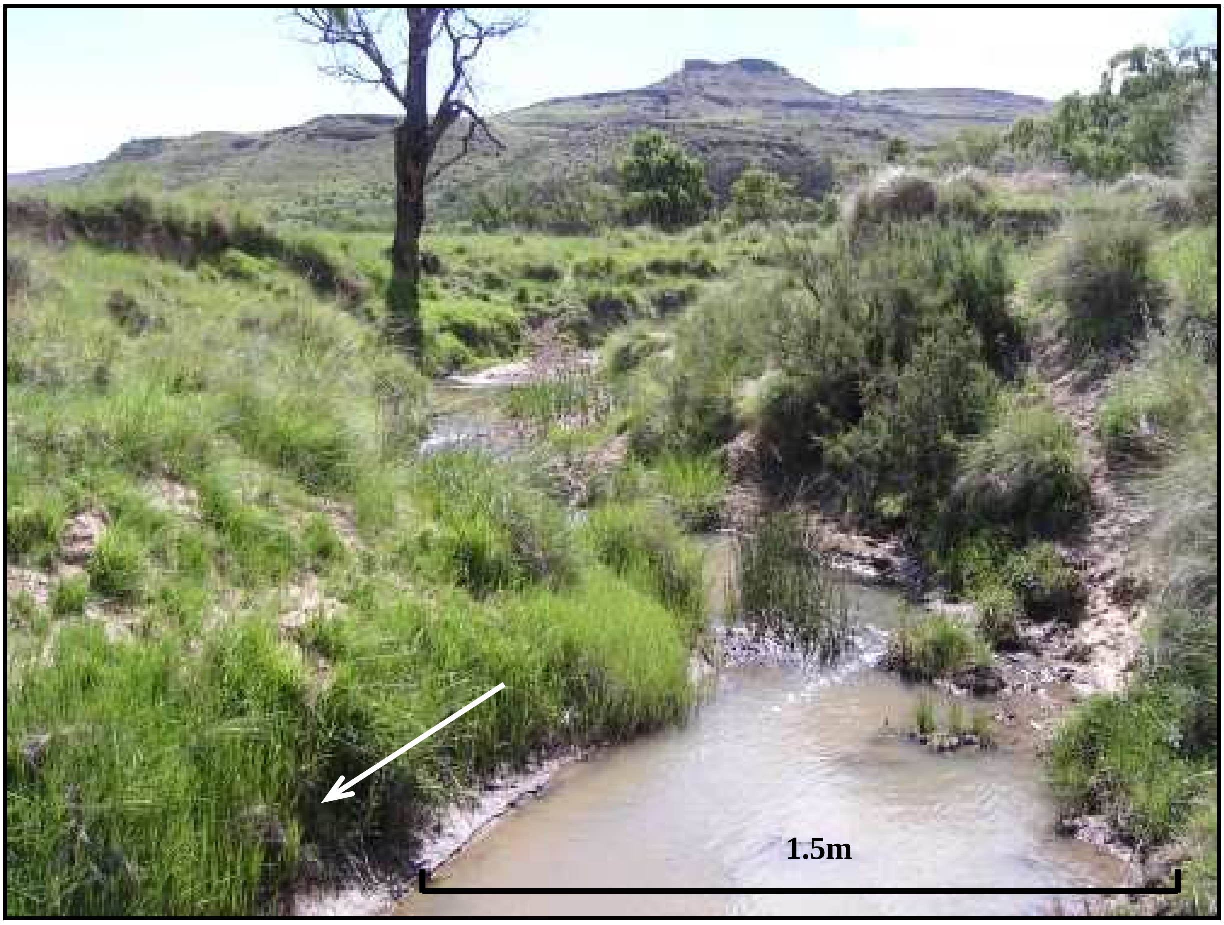

Figure 6.14 Cedarville natural Site C2 showing channel form and sandy soils

The natural Site C2 comprises of unconsolidated material with the soils visually seen to have a high sand content, in strong contrast to the darker, finer grained, clayish soils of Site C1. The sandy soils at Site C2 are a result of the sandstone parent material dominating the area. As a result the banks are friable and loose underfoot in sections, with limited groundcover. However, bank sections which are well covered by vegetation, are effectively bound by the short groundcover (Figure 6.14). The natural site contains scattered individuals of alien invasive trees from the *Salix* family growing along the banks at various sections. Figure 6.15 shows the strongly meandering nature of the stream channel at the site. At the time of survey the average channel depth of the study reach was 3.4m, with the average width being 10.7m. The width of water within the channel ranged from 0.8m to 1.9m across the ten transects, with maximum water depths from 0.05m to 0.38m at the time of survey.

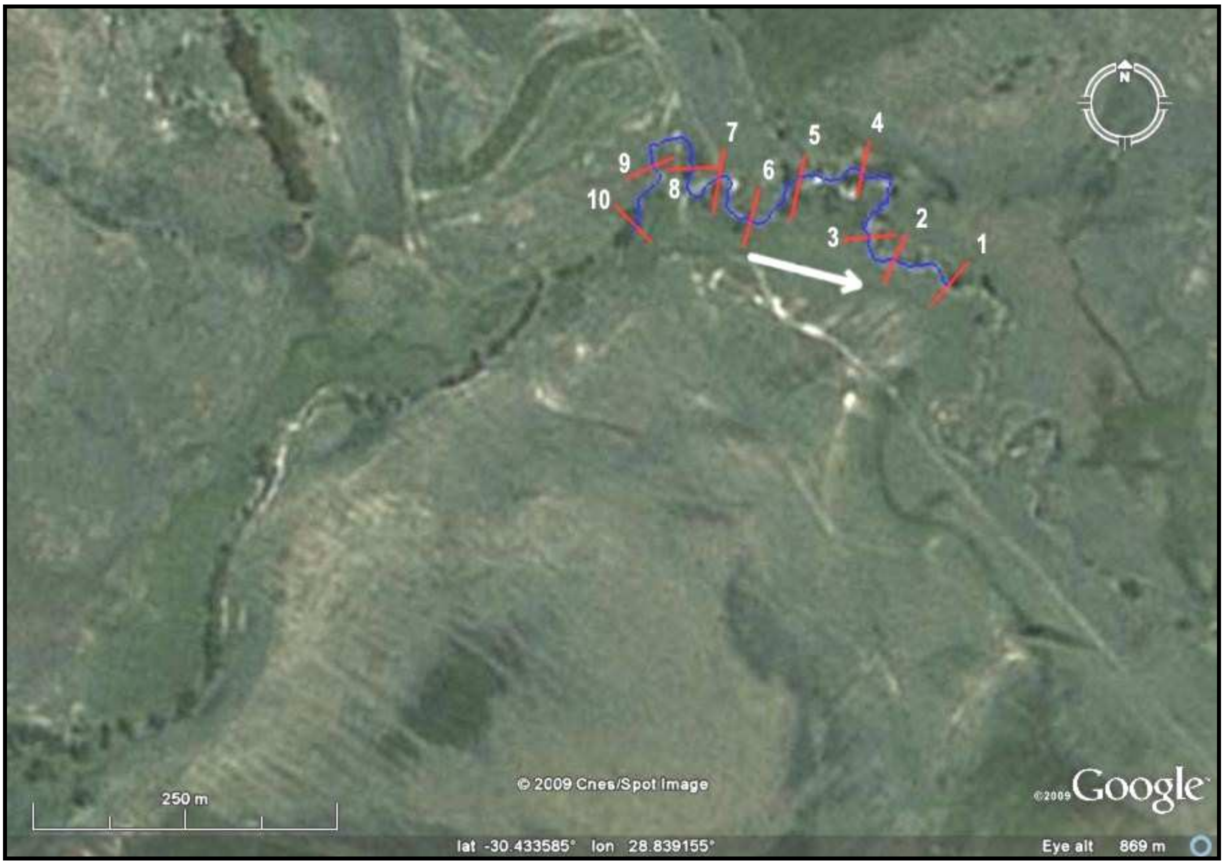

Figure 6.15 Aerial view of Site C2 study reach and MRHS/cross-profile transects 1-10

6.2.7 Cedarville IAP infested Site C3

Figure 6.16 Cedarville IAP infested Site C3 showing density of wattle invasion

IAP infested Site C3 falls 1.4km upstream from Site C2, with Site C3 being situated above the confluence of another tributary (Figure 6.3). The banks and channel bed of Site C3 are comprised of the same soils of high sand content as Site C2. Large boulders were present, individually scattered along certain sections of the river reach. Consolidation of the sandy banks was very poor under the canopy of invasive wattle due to the lack of binding groundcover (Figure 6.16). The invasive wattle was only present on the banks of the riparian zone, and within the channel. Beyond the stream banktops the vegetation reverted to grassland (Figure 6.17). At the time of survey the average channel depth of the study reach was 4.1m, with the average width being 9.9m. The width of water within the channel ranged from 0.9m to 2.6m across the ten transects, with maximum water depths from 0.05m to 0.35m at the time of survey.

Figure 6.17 Aerial view of Site C3 study reach and MRHS/cross-profile transects 1-10

6.3 Limitations of the field sites

A limitation found with the fieldwork component of the research was the lack of availability of appropriate sites. The first ideal would be to find sites of all three criteria identified in Section 6.1 (IAP infested, natural and IAP cleared), along reaches of similar type on the same river. This would ensure similar catchment and site variables and thus hydrogeomorphological controls acting on the site, such as valley form, bed gradient, runoff and sediment regimes (Figure 3.3). The second ideal would be to have multiple replicate sets of these three site groupings across a variety of regional locations to gain a statistically significant sample.

Due to commercial plantation forestry industry regulations, no densely IAP infested sites were found within the extensive area of commercial forestry property made available for the study. Equally, sites which appeared natural and which had undergone minimal impact were difficult to find within commercial forestry areas. An IAP infested site (Site U1) was found on neighbouring private land, but no natural site could be paired with it along the same stretch of river. While the IAP cleared Sites U3 and U4 were on the same river, they were far upstream, with valley form and gradient varying within the mountainous region of the sites (Figure 6.2). It was found that even within close proximity, streams within adjacent valley lines were influenced by different geological formations, valley form, bed gradient and stream size. As a result of this difficulty, sites of all three criteria were not found with similar physical controls and character.

Conversely at the Cedarville sites it proved difficult to find a site which could be considered natural, given the widespread occurrence of wattle infestations along watercourses of the area. The most natural site that could be found (Site C2) still contained sparsely scattered individuals of the *Salix* family growing along the riparian banks. In contrast to the clay rich dolerite derived soils of the densely IAP infested Cedarville Site C1, a key site, the natural site described above was found 8 km away in a valley dominated by sandstone bedrock and sandy soils (Figure 6.3). However Site C3, with a less dense degree of IAP infestation than Site C1, was found 1km upstream of Site C2 on the same river.

The second limitation of the fieldwork was the loss of accuracy in GPS signal beneath the dense canopy of the woody IAPs within the riparian zone, particularly within closed valleys. This introduced difficulties and errors in the production of the morphological maps and channel cross section profiles. The results in Chapter 7 have been analysed and interpreted in the light of these limitations.

6.4 Development of a Method of River Assessment

The approach developed for the assessment of the sites across the two locations utilised three methods of survey;

- the Modified River Habitat Survey (MRHS) developed by the author from the UK RHS,
- river cross profiles, and
- morphological unit mapping (Table 6.1).

Due to time and budget constraints, morphological unit mapping was performed only at the Umvoti sites. The river survey methods utilised are explained further in the following Sections 6.4.1 to 6.4.3.

At each river surveyed a 500m study reach comprising 10 transects at 55m intervals was established (Figures 6.5, 6.7 and 6.9). The MRHS was performed along the 500m study reach, with certain features being noted at each transect intersection point. At each transect a cross profile was taken utilising a mapping grade Trimble Pro-XRS GPS receiver and TSC1 data collector. Following differential correction, this setup provides sub metre accuracy of less than 500mm in the horizontal (x and y) plane and less than 1000mm in the vertical (z) plane. The differential GPS was also used to capture the stream form and the boundaries of the channel for the entire length of the 500m study reach at each site. Finally, detailed mapping of the morphological units or hydraulic biotopes, as well as bank features was undertaken along three short study reaches at each of the Umvoti sites U1 to U3.

6.4.1 Modified River Habitat Survey

The UK River Habitat Survey (Section 5.2.1 and Appendix 2) forms the basis of the approach that was developed during this study for the assessment of the overall physical character and habitat quality of the field sites. The Modified River Habitat Survey (MRHS) form produced for local stream assessment has maintained a similar structure, layout and methodology to the UK RHS but with various changes to suit South African conditions, and the needs of the particular study. The ‘standard’ Flow Biotopes for South Africa proposed by Rowntree and Wadeson (1999) were utilised to tailor the RHS for South African conditions. A copy of the MRHS form can be found in Appendix 1.

The MRHS captures qualitative and quantitative data within 18 sections of the survey form (Appendix 1). The codes of the MRHS spot-check transect key (Table 6.3) are utilised to aid filling in of the survey form. The spot-check key makes use of the hydraulic biotopes outlined by Rowntree and Wadeson (1999) (Table 5.1), which are used by the surveyor when filling in the Flow type/Hydraulic biotope of the channel for each belt transect in Section F on page 2 of the MRHS (Appendix 1). The quantitative data and qualitative information gathered by the stream habitat surveys across the numerous field sites, ranging from natural condition to rehabilitated and then infested, was used to assess the influences of the Invasive Alien Plants on the hydrogeomorphology of riparian systems. Quantitative data included measurements of channel dimensions at each of the ten transects utilising a tape measure and measuring staff. The MRHS method includes the use of site photographs and general observations in recording and assessing riparian condition.

Table 6.3 Modified RHS – Transect key code[1] to note features present at each transect

MODIFIED RIVER HABITAT SURVEY TRANSECT KEY					
F. PHYSICAL ATTRIBUTES					
BANKS					
BANK MATERIAL		**BANK MODIFICATIONS**		**MARGINAL & BANK FEATURES**	
NV	Not visible	**NK**	Not known	**NV**	Not visible
BE	Bedrock	**NO**	None	**NO**	None
BO	Boulder	**RS**	Resectioned	**EC**	Eroding cliff (earthy)
CO	Cobble	**RI**	Reinforced	**SC**	Stable cliff (earthy)
GS	Gravel/sand	**PC**	Poached	**PB**	Unvegetated point bar
EA	Earth (crumbly)	**BM**	Artificial berm	**VP**	Vegetated point bar
PE	Peat	**EM**	Embanked	**SB**	Unvegetated side bar
CL	Sticky clay			**VS**	Vegetated side bar
				NB	Natural berm
CHANNEL					
CHANNEL SUBSTRATE		**CHANNEL MODIFICATIONS**		**CHANNEL FEATURES**	
NV	Not visible	**NK**	Not known	**NK**	Not known
BE	Bedrock	**NO**	None	**NO**	None
BO	Boulder	**CV**	Culverted	**EB**	Exposed bedrock
CO	Cobble	**RS**	Resectioned	**RO**	Exposed boulders
GP	Gravel / Pebble	**RI**	Reinforced	**VR**	Vegetated rock
SA	Sand	**DA**	Dam / Weir	**MB**	unvegetated mid-channel bar
SI	Silt	**FO**	Ford (man-made)	**VB**	vegetated mid-channel bar
CL	Clay			**WD**	Woody debris
EA	Earth			**DW**	Damming of channel by woody debris
PE	Peat				
FLOW TYPE / HYDRAULIC BIOTOPE					
PO	Pool	**GL**	Glide	**CA**	Cascades
RI	Riffle	**CH**	Chute	**WF**	Waterfall
RU	Run	**RA**	Rapid	**BA**	Backwater
G. BANKTOP LAND USE AND VEGETATION STRUCTURE					
WL	Wetland	**BR**	Invasive Bramble	**FB**	Fire break (bare earth)
GR	Grassland	**BW**	Invasive Bugweed	**RD**	Rock/scree
NO	Thicket	**WA**	Invasive Wattle	**IL**	Irrigated land
NK	Shrubland	**EG**	Exotic grasses	**PT**	Pasture
IF	Indigenous forest	**PP**	Plantation Pine	**TL**	Tilled land
		PW	Plantation Wattle	**DR**	Dirt road
		PE	Plantation Eucalypt		

6.4.2 Mapping of Morphological Units/Hydraulic Biotopes

At Sites U1, U2 and U3 accurate maps of stream, bank and vegetative features were produced at three representative reaches of 20m length, within each 500m study reach (Figures 6.5, 6.7 and 6.9). The final methodology utilised combined methods extracted from King and Schael (2001) and Rowntree and Wadeson (1999).

[1] The UK RHS key utilises the bank features "Eroding cliff" and "Stable cliff". These terms were retained in the development of the MRHS key for use in the study, but are not commonly utilised in South Africa. Within this dissertation the term “cliff bank” will be utilised to refer to these near vertical banks.

When mapping streams King and Schael (2001) distinguished between flow types and morphological units, producing separate maps for each. They categorized hydraulic flow types as the lowest level of hierarchy in stream geomorphology, in the form of features such as riffles, runs or rapids. Morphological units were channel features at the next scale up, such as waterfalls, pools or secondary channels (King and Schael, 2001).

In this study pools and waterfalls have been lumped with flow types, such as riffles and runs, in accordance with the hydraulic biotope concept (Rowntree and Wadeson, 1999). The hydraulic biotope concept has already been integrated into the river habitat survey method (MRHS) of this study. Thus in the mapping of representative reaches within this study the method utilised was to lump hydraulic flow types and morphological units into a single map along with bank features such as undercut, rocky or earthy, and channel features such as side bars or point bars. Features of special interest with respect to the study of the influence of IAPs on riparian zones were also included, such as debris dams. Beyond the section of bank that interacts directly with the stream during normal flows, the terrain was mapped according to the overlying groundcover, land use or extent of soil erosion.

The rationale was that mapping all features into a single map would best highlight trends in common features, and changes associated with IAP infested sites versus the non-infested sites. Based on the literature survey, it was hypothesised that the following features are more common within riparian zones after IAP invasion has taken place;

- steep undercut banks,
- narrow over-deepened channels,
- woody debris choking the channel,
- woody debris dams blocking the channel,
- loss of indigenous riparian vegetation on streambanks, and
- increased soil erosion within the riparian zone.

Most of the above features can be observed qualitatively at the field sites but the aim of the morphological mapping was to place quantitative numbers and distributions to these features within the riparian zone. In addition it was intended that the mapping would link the prevalence of these features to the presence, density and distribution of IAPs as well as possibly highlighting other common changes brought on by IAP invasion.

Once fieldwork was initiated it was found that beneath the dense canopy of invasive alien wattle growth within the riparian zone of the infested site, the GPS lost signal strength and was thus not sufficiently accurate to map fine-scale, individual morphological units and features of special interest within the channel. As a result, methods of mapping morphological units by GPS, as utilised by King and Schael (2001) and Rowntree and Wadeson (2005) were found to be unsuitable for this study.

In the absence of useable GPS data for the infested sites, a manual methodology was developed for mapping the morphological units. Utilising a quadrat, features would be mapped manually on graph paper, and then digitised and geo-referenced using a digitising tablet and GIS. A 2m x 2m quadrat (Figure 6.18) was constructed of wood, producing four squares of $1m^2$ each. Tape measures were attached to all ribs of the quadrat for quick and accurate measuring. Utilising multiple 20m tape measures, a grid was set up along the 20m reach to be mapped. The quadrat then had reference lines along which it could be moved to cover the entire 20m reach in a consistent grid pattern.

Figure 6.18 Wooden quadrat being utilised to map morphological features

Each of the four $1m^2$ sections within the quadrat was represented as 100 squares on graph paper, with the result that a 100x100mm grid on the ground was represented by one square on the graph paper. In this way features were mapped manually along each 20m reach, to a potential accuracy of 100mm. The GPS was utilised to capture the corners of the 20m study reach so that the graph paper sketch could be geo-referenced once digitised.

Utilising a digitising tablet the graph paper sketches were digitised and imported into the Arcview GIS package. The digitised sketches were geo-referenced by the GPS readings, thus forming a GIS dataset. The maps were exported from Arcview into a drawing program to produce the final output of morphological maps shown in Section 7.2. Due to time and budget limitations the mapping of morphological units was limited to the Umvoti sites U1 to U3.

6.4.3 Channel cross profiles

Cross profiles were taken utilising a mapping grade differential GPS at each of the ten transects utilised during the River Habitat Survey. The cross profiles were recorded so that the relationships between channel depth and width could be explored, potentially indicating the impacts of woody IAP infestation on bank steepness and channel incision. The GPS was found to produce a similar loss of accuracy during the cross profile capturing at the infested sites, but as the cross profiles mapped larger features than the fine scale features of the morphological mapping, it was felt that the GPS accuracy should be sufficient to capture the general trend of channel dimension across the transects.

7. RESULTS

The tools and methods of survey utilised during the field sampling fall into three categories; the Modified River Habitat Survey, the Mapping of Morphological Units and Hydraulic Biotopes, and the cross profile analysis.

7.1 Modified River Habitat Survey

The Modified River Habitat Survey (MRHS) (Appendix 1), developed and described in Section 6.4.1, was performed at all sites across both study locations. In Sections 7.1.1 to 7.1.4 graphs were produced of selected data from the completed MRHS forms (Figures 7.2-7.9). Figure 7.1 is a cross-section which illustrates the terms used to define the location of the surveyed features which were analysed in Sections 7.1.1 to 7.1.4.

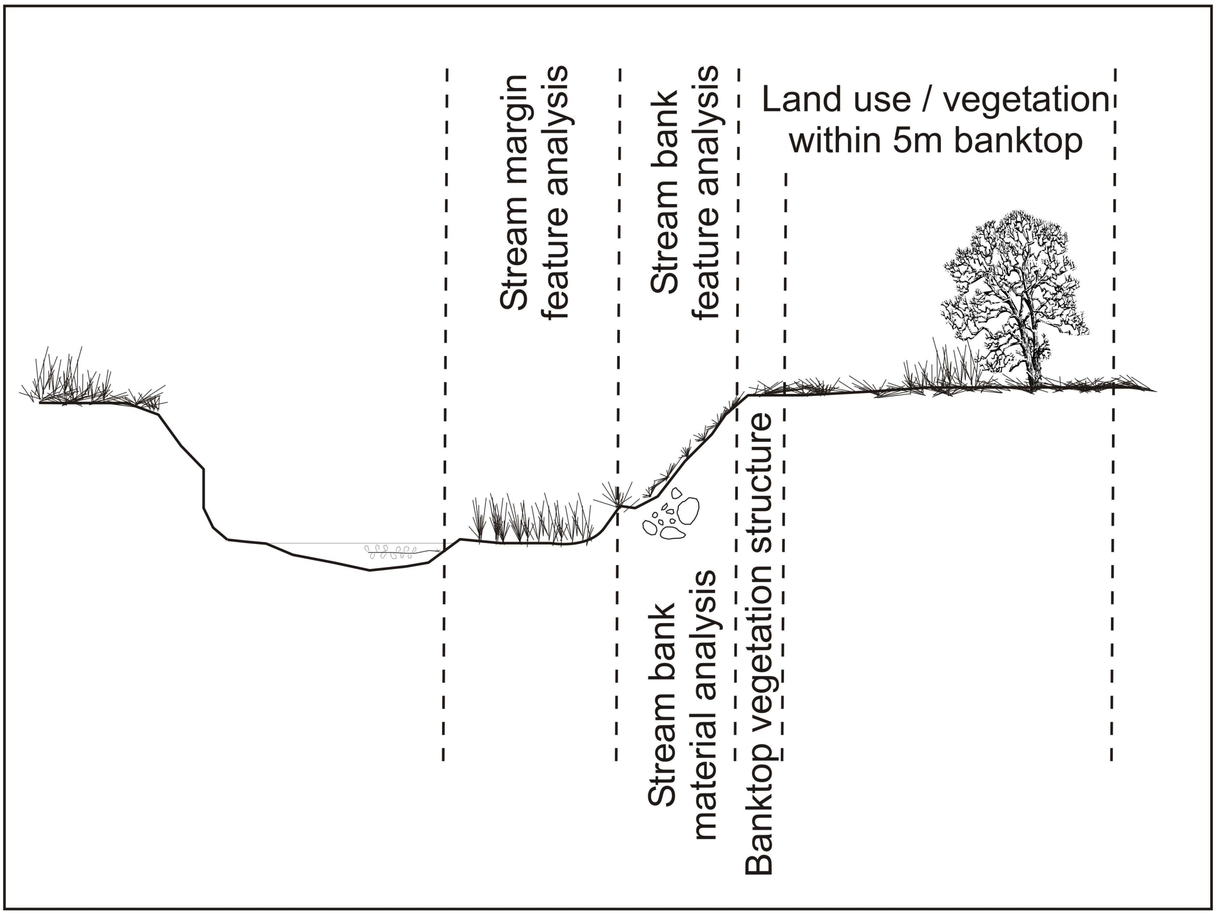

Figure 7.1 Channel cross-section illustrating definitions used in analysis of selected MRHS features surveyed

The data is graphed to explore potential trends collected by the MRHS from the site repetitions across the two study regions. The figures illustrated by the graphs represent a total number of each feature from all 10 transects at each site, but split between occurrence on the left or right bank of the channel. The transect key code in Table 6.3 outlines the variables whose numbers of occurrence are illustrated in the following graphs (Figures 7.2-7.9). Only those features that were present at the sites are included in the graph. For example at the Umvoti sites (Figure 7.2) the dolerite-derived streambank soils were captured within the 'Earth' class (Table 6.3: EA = Earth (crumbly)), while the streambank material graph of the Cedarville sites (Figure 7.3) includes the 'Gravel/sand' class (Table 6.3: GS = Gravel/sand) to account for the sandstone-derived soils of Sites C2 and C3.

7.1.1 Streambank material analysis

Figures 7.2 and 7.3 graph data from Section F. of the MRHS form which covers the physical attributes of the sites at each of the ten transects. The graphs show the distribution of streambank material types across all sites, with the Cedarville region sites being compared with the Umvoti region sites across the two graphs. This format is followed throughout Section 7.1. The purpose of the streambank material analysis is to establish possible influences on stream form by the different bank materials across the sites. The streambank material class 'Earth' (Table 6.3) refers to banks comprised predominantly of soil, in contrast to the "Earth/Cobble" or "Boulder/Earth" classes where boulder or cobble are omnipresent.

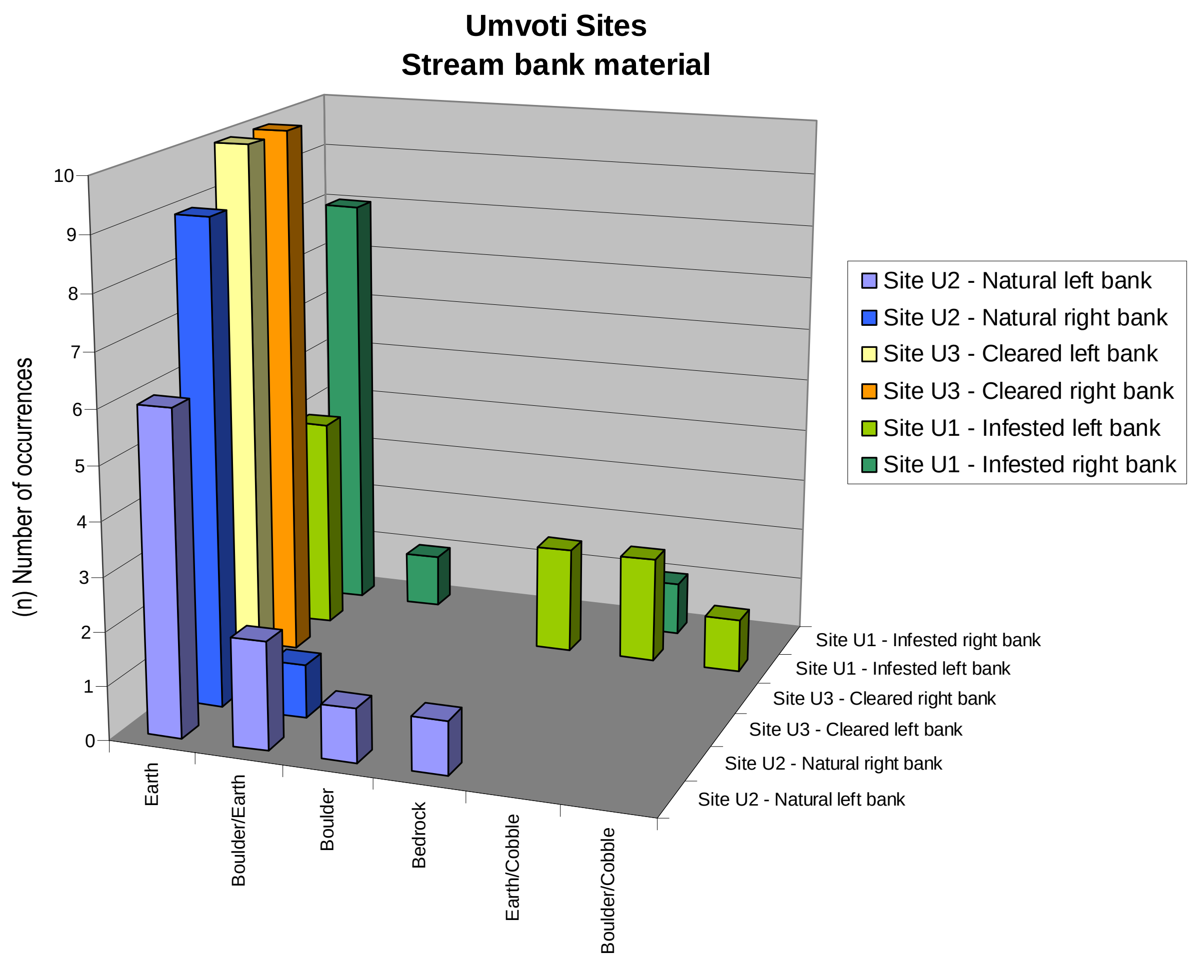

Figure 7.2 Comparison of streambank material across the Umvoti sites

From Figure 7.2 it can be seen that at the Umvoti sites the predominant bank material is earth. IAP cleared Site U3, the wetland site, shows no presence of cobble, boulder or bedrock, while the IAP infested Site U1 showed a presence of bedrock at two transects, with cobble and boulders being present within the earth banks at others. The natural Site U2 reflected the presence of bedrock at a single transect, with other transect points containing boulders but no cobble. This analysis illustrates that at site U3 the channel is cut through finer alluvium, which allows the channel greater flexibility in developing natural meanders and base level change. Stream form processes at Sites U1 and U2 will, to some degree, be influenced by the presence of boulders and cobbles of parent rock within the banks and bed material, as well as the temporary base levels of bedrock.

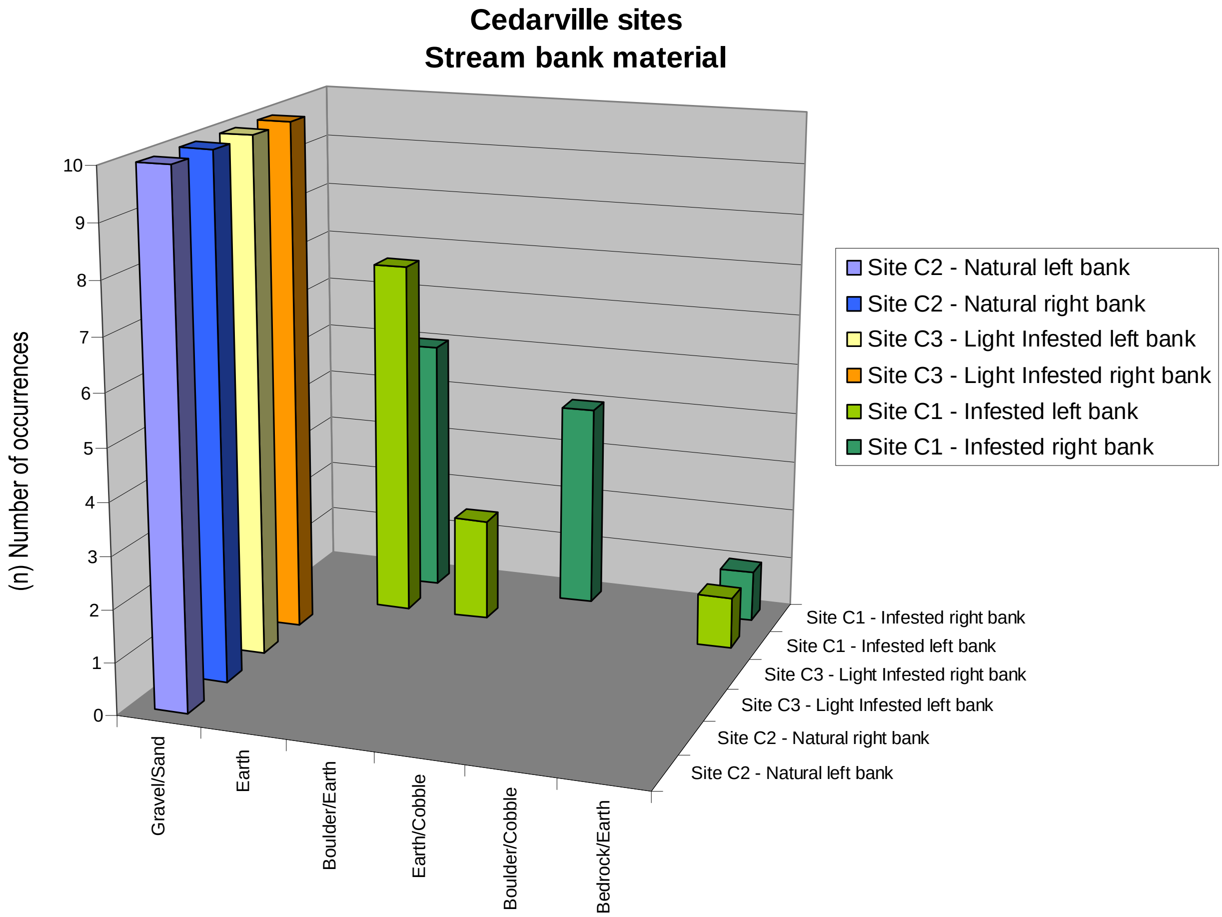

Figure 7.3 Comparison of streambank material across the Cedarville sites

At the Cedarville sites the site observations noted in Section 6.2 are reinforced by Figure 7.3 where it is seen that the banks at Sites C3 and C2 are comprised exclusively of sand and gravel of sandstone parent rock origin. No bedrock was visible within the channel bed. By contrast IAP infested site C1 shows the presence of cobble boulders and bedrock with banks comprised of earthy material most likely of doleritic origin. Similar to the Umvoti sites, the Cedarville IAP infested site takes the form of a bedrock dominated system, where meander form and bed erosion is influenced by bedrock and the presence of parent material within the banks. Section 7.1.5 and Figure 7.10 explore the relationships between the bedrock dominated sites and the height-width ratios of the channels.

7.1.2 Stream margin and streambank feature analysis

Figures 7.4 and 7.5 illustrate the presence of bank features and features within the marginal zone of the river, such as side bars and natural berms. With the Umvoti set it can be seen that the natural Site U2 has a lower total number of stable and eroding cliff banks than the IAP infested and IAP cleared sites.

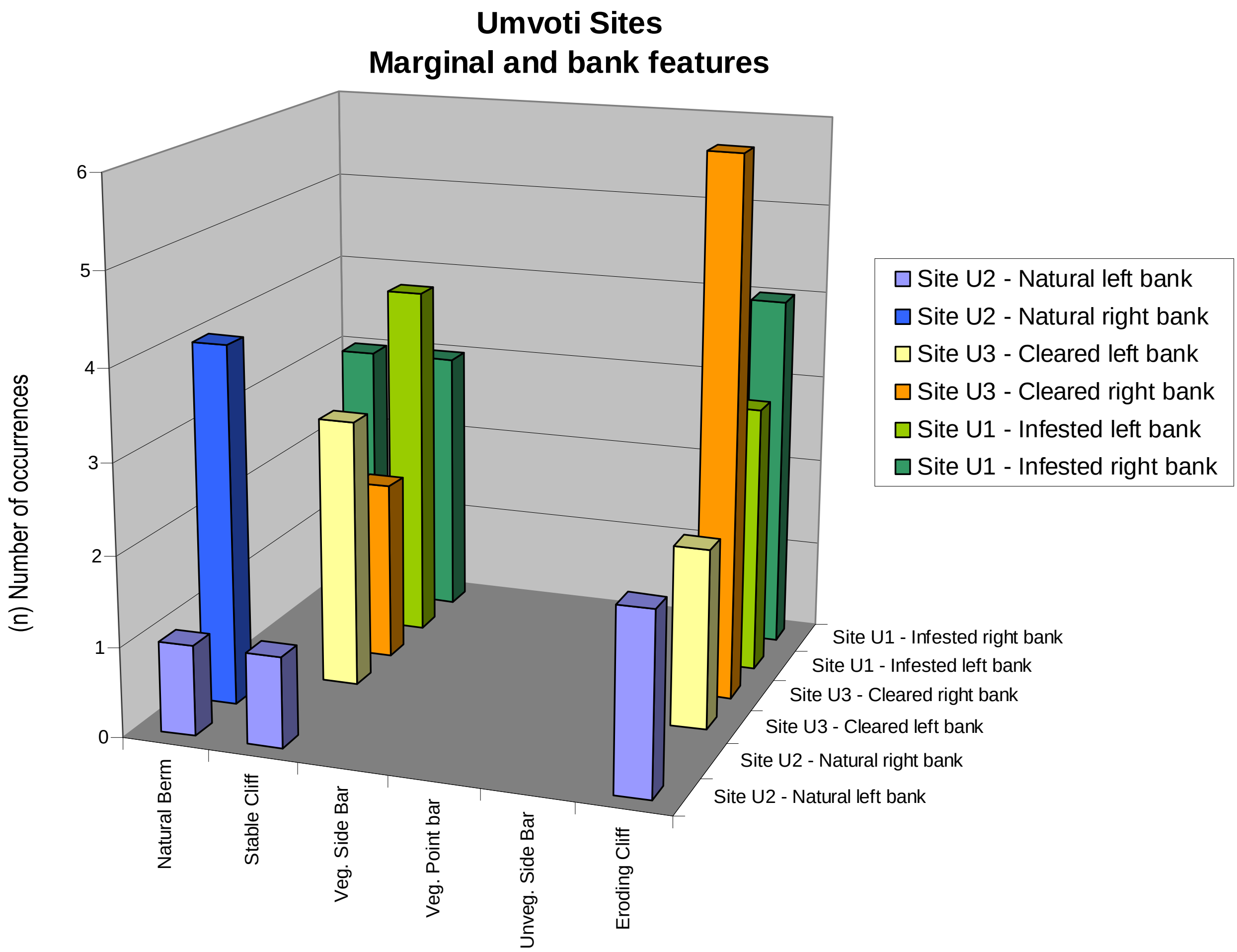

Figure 7.4 Comparison of stream marginal and bank features across the Umvoti sites

At the Cedarville sites shown in Figure 7.5, it can be seen that a similarly low distribution of stable cliff banks are present across the sites, but that there is a much higher prevalence of eroding cliff banks at the IAP infested sites than the natural site.

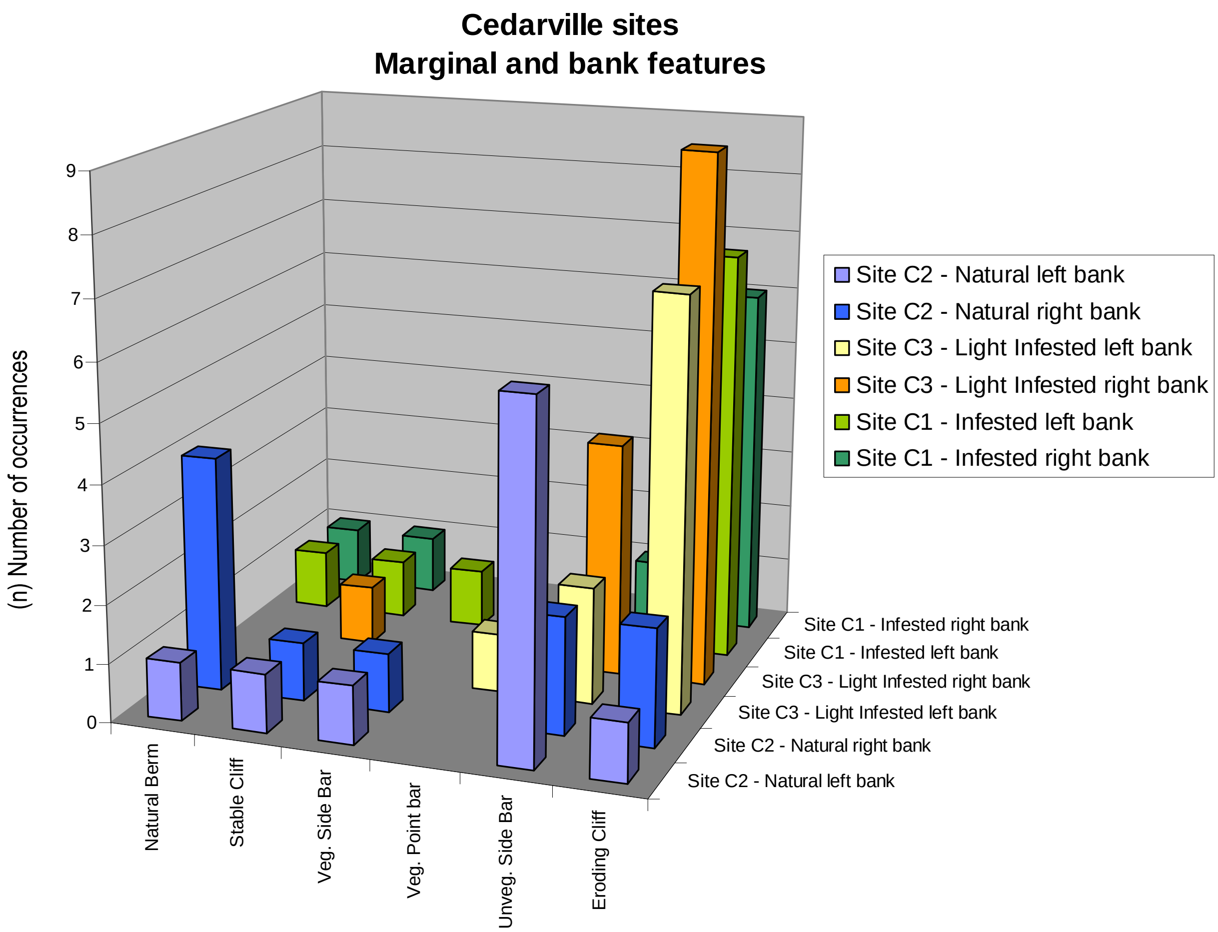

Figure 7.5 Comparison of stream marginal and bank features across the Cedarville sites

7.1.3 Banktop vegetation structure analysis

At the Umvoti sites it can be seen in Figure 7.6 that at IAP infested Site U1 the banktop vegetation was dominated by a Bramble and Bugweed mix. wattle with bare earth beneath was the second most prevalent vegetation cover present on the banktops of the infested transects. In addition to the lack of groundcover, wattle on the banktops has relevance as the literature points toward the presence of large woody IAPs present on bank tops potentially causing bank instability if the rooting depth is less than the bank height (Section 4.2). At the IAP cleared Site U3 a Bramble, Bugweed and wattle mix was prevalent at two of the twenty banktops, with the remainder of the banktops being comprised of grassland. This shows the prevalence of a small amount of invasive alien plants which have returned after clearing. At the natural Site U2 the banktops were almost exclusively covered in grass species, however the corner edge of one of the commercial forestry plantation blocks reached the macro-channel banktop at one of the transects. This can be seen in the aerial photograph image of Site U2 in Figure 7.4 at the upstream end of the study reach.

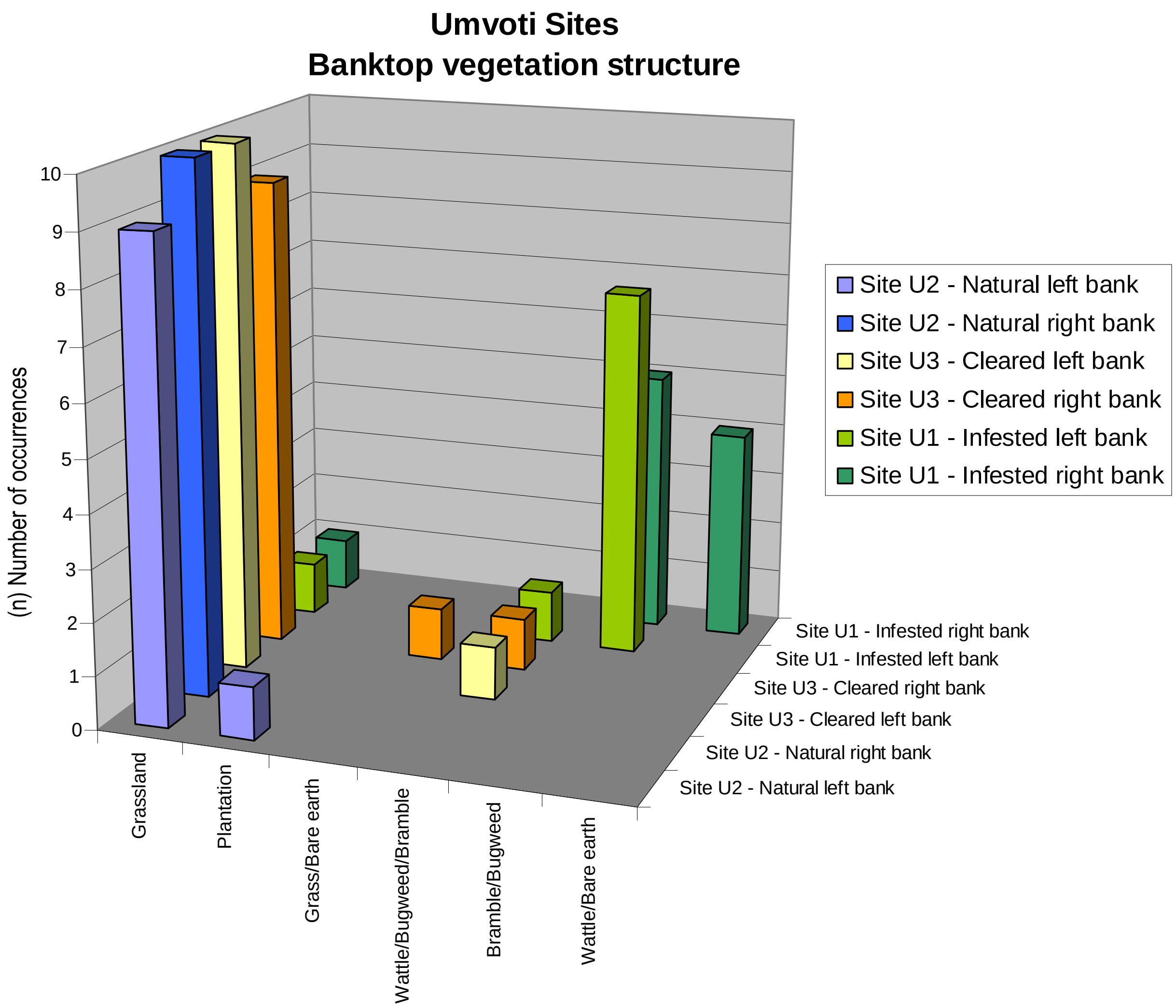

Figure 7.6 Comparison of banktop vegetation structures across the Umvoti sites

Similarly, Figure 7.7 shows that the banktops at the Cedarville natural Site C2 were dominated almost exclusively by grassland species. However, scattered individuals of invasive *Salix* species were present which were not picked up by the 55m interval transect samples of the MRHS. However, the presence of these species was noted in other sections of the survey form. The density of invasive wattle buffering the length of the riparian zone at Site C1 gave way to grassland in one section, shown by Figure 7.7, where one transect and a second banktop on the left bank was comprised of grassland. The dominance of invasive wattle along the rest of the banks of Site C1 is shown graphically. The fact that Site C3 was less densely infested by invasive wattle than C1 is shown in Figure 7.7 by the high occurrence of the wattle/grass combination of banktop vegetation. The wattle being present in lower density allowed grass to grow at some sections beneath the canopy of the invasive tree species.

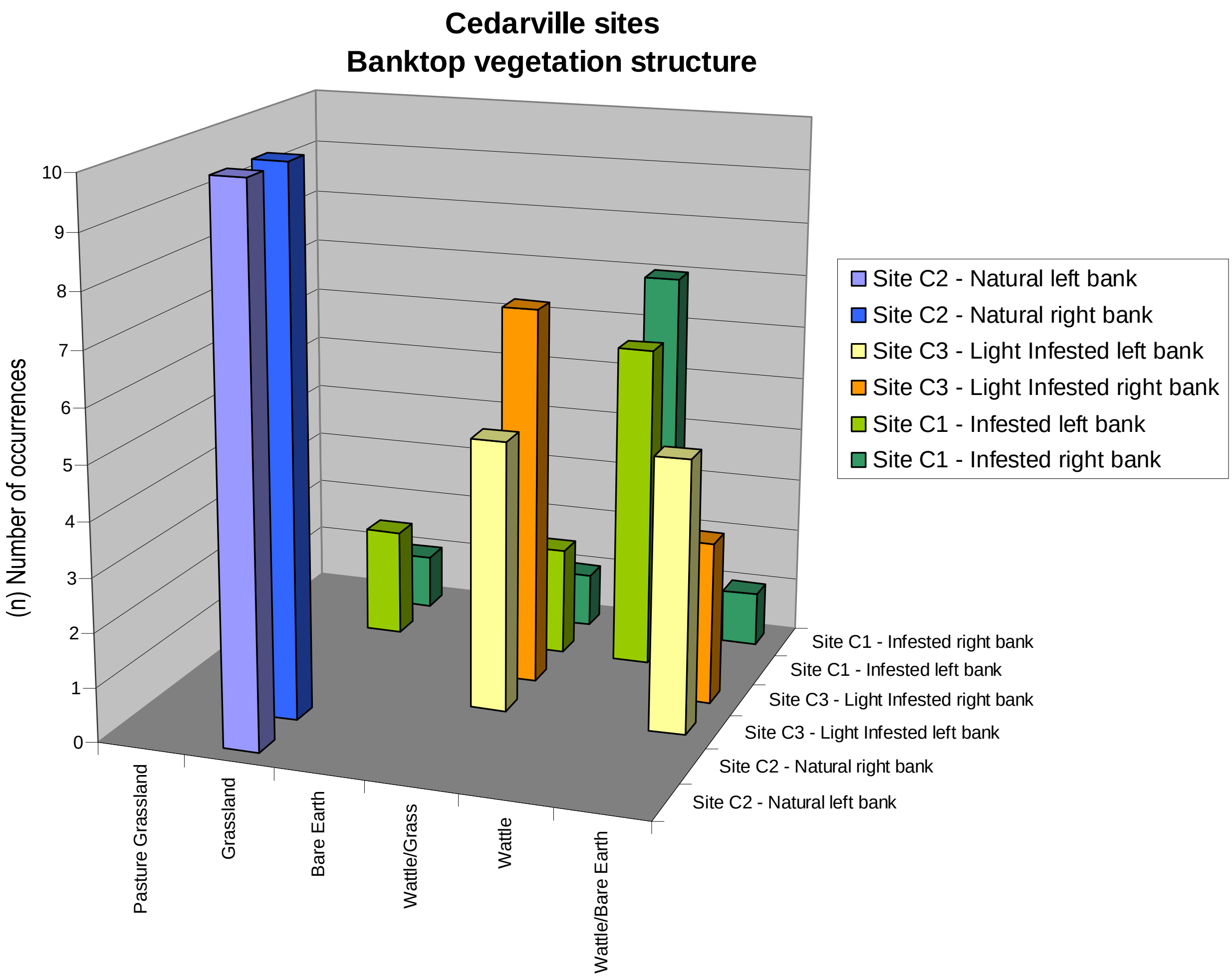

Figure 7.7 Comparison of banktop vegetation structures across the Cedarville sites

7.1.4 Landuse or vegetation within 5m of the banktop

Figure 7.8 shows that at IAP infested Site U1 beyond the banktop wattle, Bugweed and Bramble continued to dominate the vegetation composition within 5m of the banktop, with grass cover present at only three of the transects 5m from the banktop. Moving away from the channel, the IAP cleared site and the natural site showed similar vegetation compositions to the banktop vegetation graph in Figure 7.6.

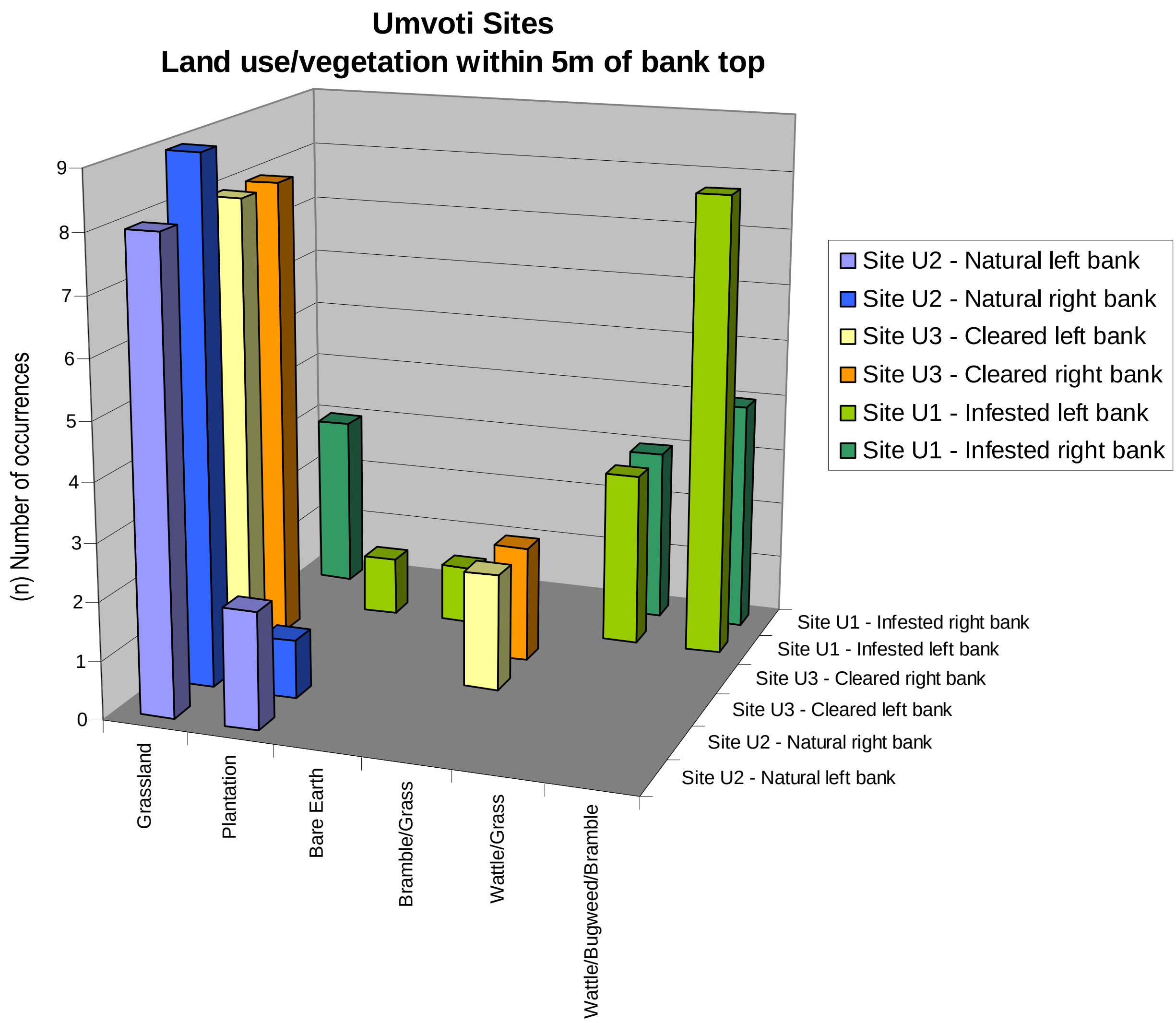

Figure 7.8 Comparison of land use/vegetation within 5m of banktop across the Umvoti sites

For the Cedarville sites grassland utilised for pasture was present within 5m of the banktop at the natural Site C2. This 'pasture grassland' differed from the predominantly natural grassland of the 'grassland' sites in that it was grassland where grazing selection and/or management has altered the grass species composition to more pastoral grasses. At the lightly infested Site C3, grassland is equally as abundant as wattle across the ten transects within 5m from the banktop (Figure 7.9). This shows that the invasive wattle infestation at C3 was in the form of a narrow band, almost confined by the banktops, which is in contrast to sites C1 and U1 where the extended area of the riparian zone was heavily infested, as shown in Figures 6.17, 6.13 and 6.5 respectively. Figure 7.9 shows that at IAP infested Site C1, grassland was present within 5m of the banktop at only one transect, at each left and right bank.

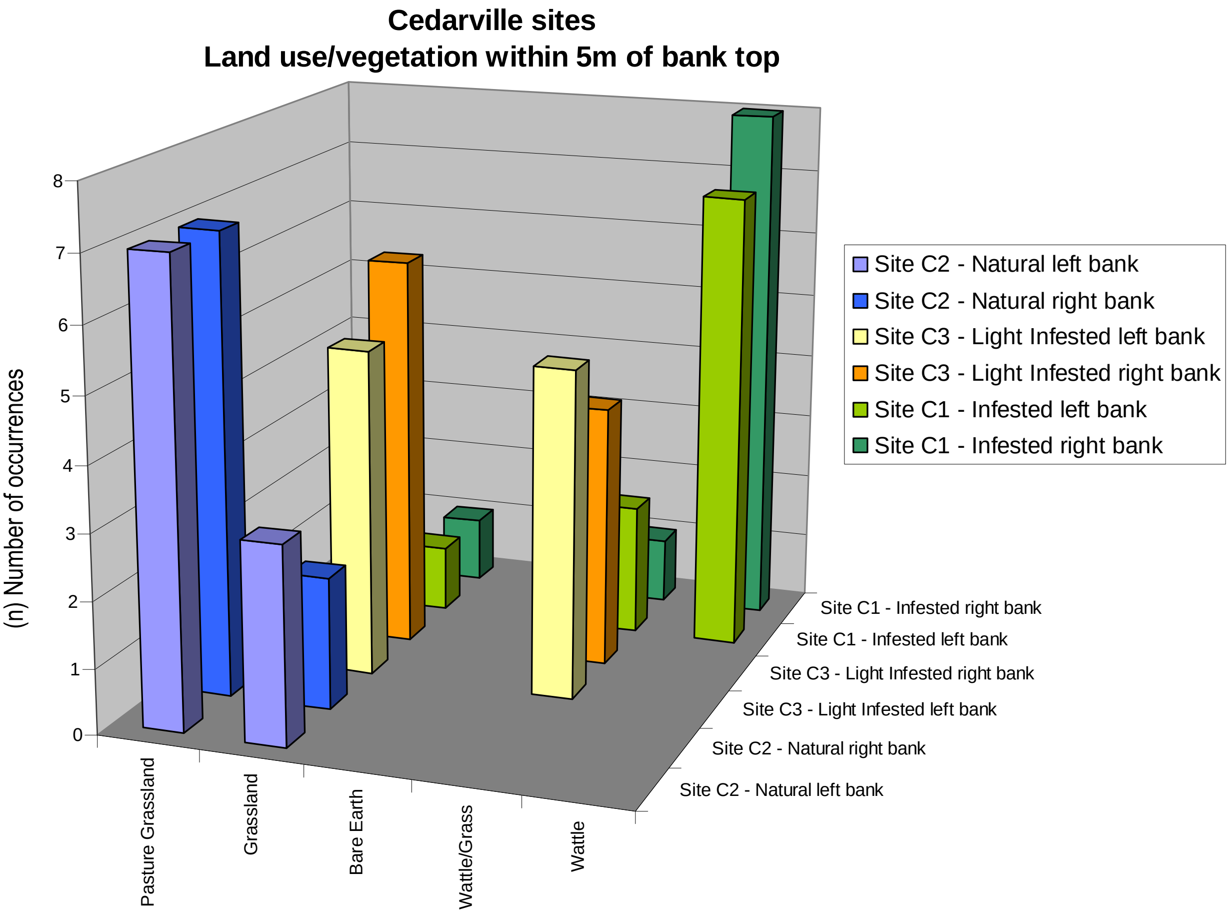

Figure 7.9 Comparison of land use/vegetation within 5m of banktop across the Cedarville sites

7.1.5 Height to width ratio analysis of channels

Section I of the MRHS (Appendix 1) captures channel dimensions, and the bedrock present at each transect. Channel dimensions were measured at each of the ten transects utilising a tape measure and measuring staff. Utilising the channel dimension data a height-width ratio[2] analysis was performed utilising a similar methodology employed by Rowntree (1991) in 'an assessment of the potential impact of alien invasive vegetation on the geomorphology of river channels in South Africa'. The method utilised by Rowntree compared the width-depth ratio of ten channel cross-sections with a vegetation rank based upon the density of woody vegetation present. The method of ranking woody vegetation employed was developed from

[2] As the study dealt with bank stability, the emphasis was on bank height rather than channel depth. In many cases left and right hand banks were of different height, with the result that bank height was greater than channel depth. Therefore the bank height was taken as an average of the left and right bank heights. This average height of the banks was then divided by the channel bankfull width producing the height-width ratio utilised in the study. Thus the conventional width-depth ratio was not utilised.

vegetation parameters affecting bank erosion and stability proposed by Thorne (1990). The method of ranking woody vegetation utilised by Rowntree was not employed in this study, however, as the sites were demarcated based on their IAP invasion status (Section 6.1) the height-width ratios were related to the degree of IAP infestation of the sites (IAP infested, IAP cleared or natural).

The results of the height-width ratio analysis are shown in Table 7.1. In this analysis the average of the left and right bank heights was taken as an indication of bank height at each transect. In terms of the average bank height and average channel width (Table 7.1), no relationship can be seen between these variables and the degree of infestation, or these variables and the alluvial or bedrock dominated nature of the stream.

A low height-width ratio (i.e. 0.3) reflects a channel which is wider in relation to it's height, compared to a higher ratio (i.e. 0.8) where for the same bank height the channel will be narrower. The calculated height-width ratios for each transect were then averaged to gain an average height-width ratio for the entire site, shown graphed in Figure 7.10 for each site.

Table 7.1 Height-width ratio of channels at the MRHS transects

Site	Variable	Transect No.										Ave	Degree of infestation	River bed type
		1	2	3	4	5	6	7	8	9	10			
Site U1	Height (cm)	260	363	154	220	205	280	265	570	515	285	312	IAP Infested	Bedrock dominated
	Width (cm)	820	370	920	670	540	570	1100	1200	980	370	754		
	Ratio	**0.3**	**1.0**	**0.2**	**0.3**	**0.4**	**0.5**	**0.2**	**0.5**	**0.5**	**0.8**	**0.5**		
Site U2	Height (cm)	80	100	125	95	70	110	90	50	50	100	87	Natural	Bedrock dominated
	Width (cm)	370	160	450	300	300	380	500	200	600	300	356		
	Ratio	**0.2**	**0.6**	**0.3**	**0.3**	**0.2**	**0.3**	**0.2**	**0.3**	**0.1**	**0.3**	**0.3**		
Site U3	Height (cm)	70	140	150	140	123	125	125	93	110	115	119	IAP Cleared	Alluvial
	Width (cm)	700	600	250	170	270	230	280	330	420	220	347		
	Ratio	**0.1**	**0.2**	**0.6**	**0.8**	**0.5**	**0.5**	**0.4**	**0.3**	**0.3**	**0.5**	**0.4**		
Site U4	Height (cm)	175	255	295	120	190	180	190	225	370	200	220	IAP Cleared	Alluvial
	Width (cm)	400	450	440	380	700	410	405	380	520	580	467		
	Ratio	**0.4**	**0.6**	**0.7**	**0.3**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.3**	**0.5**		
Site C1	Height (cm)	89	240	440	200	190	265	140	210	255	350	238	IAP Infested	Bedrock dominated
	Width (cm)	1020	550	1050	950	700	780	850	580	690	850	802		
	Ratio	**0.1**	**0.4**	**0.4**	**0.2**	**0.3**	**0.3**	**0.2**	**0.4**	**0.4**	**0.4**	**0.3**		
Site C2	Height (cm)	383	400	385	285	360	345	370	380	220	315	344	Natural	Alluvial
	Width (cm)	1150	960	920	940	1600	1100	1100	960	980	950	1066		
	Ratio	**0.3**	**0.4**	**0.4**	**0.3**	**0.2**	**0.3**	**0.3**	**0.4**	**0.2**	**0.3**	**0.3**		
Site C3	Height (cm)	530	530	440	433	410	390	310	280	365	370	406	IAP Infested	Alluvial
	Width (cm)	920	810	820	880	750	980	1300	1340	810	1300	991		
	Ratio	**0.6**	**0.7**	**0.5**	**0.5**	**0.5**	**0.4**	**0.2**	**0.2**	**0.5**	**0.3**	**0.4**		

Figure 7.10 illustrates the relationships between the bank height-width ratio, presence of IAP infestation and the alluvial or bedrock dominated nature of the stream at the sites surveyed. From analysis of the chart there appears to be a stronger relationship between the height-

width ratio and the extent of woody IAP infestation than to the presence of an alluvial or bedrock dominated system. The bedrock dominated sites have the highest and lowest height-width ratios, while the two natural sites have amongst the lowest height-width ratios. Infested Site C1 forms an outlier which doesn't conform to the trend that the infested (U1, C1, C3) and previously infested (U3, U4) sites have greater maxima of height-width ratios than the natural sites.

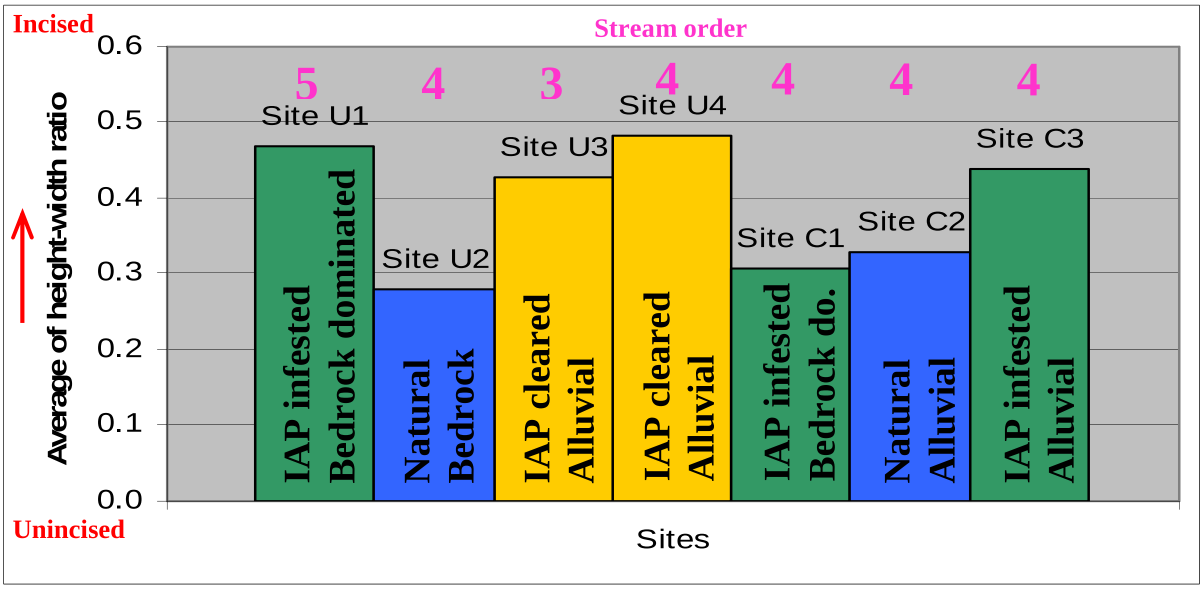

Figure 7.10 Average of height-width ratio of channels per site

In the analysis of Figure 7.10, infested Site C3 and natural Site C2 form a good comparison as the stream reaches fell within close proximity, with very similar physical attributes. However, although they fell on the same stretch of river, Site C2 lies below the confluence of a tributary, so would receive slightly higher streamflows than C3 (Figure 6.3). The height-width ratios reflected in Figure 7.10 show that relative to channel depth, the upstream infested Site C3 is narrower and more incised than the natural Site C2. All of the IAP infested and IAP cleared sites have channels that are narrower in relation to depth than the natural sites, barring IAP infested Site C1. No correlation can be seen between stream order and the degree of incision of the channels (Figure 7.10).

To further explore possible relationships between the average channel heights and widths at each transect, and the degree of IAP infestation or river bed type (Table 7.1) the data was graphed on a scatter plot (Figures 7.11and 7.12). Figure 7.11 plots channel height and width for each of the ten transects across all of the seven sites with the point symbols categorised by degree of infestation. The scatter plots showed no significantly clear relationships, however some inferences could still be made. The most apparent relationship is shown by the cluster of plots from the Umvoti IAP cleared Sites U3 and U4 symbolised by the blue squares. These sites both took the form of small channels flowing through wide, flat, open valley bottoms (Figures 7.5 and 7.7). Another cluster, though more indistinct, can be seen by Sites C2 and C3 which fell on the same stretch of river (Figure 6.3) near Cedarville. This appears to indicate a stronger relationship between the height-width and the local hydrogeomorphological drivers of channel form at the sites, rather than the degree of infestation.

The two most densely IAP infested sites U1 and C1 show the weakest clustering betweens all the transects of each site, with points spread across the graph. This may indicate that IAP infested reaches cause instability and erosion of the channel banks at certain sections, resulting in non-uniformity in channel dimensions across the site. In contrast the tight clustering of the transects of natural Site U2 shows that the channel dimensions at all ten transects were similar, showing uniformity, possibly explained by bank stability and good bank vegetative cover limiting erosion.

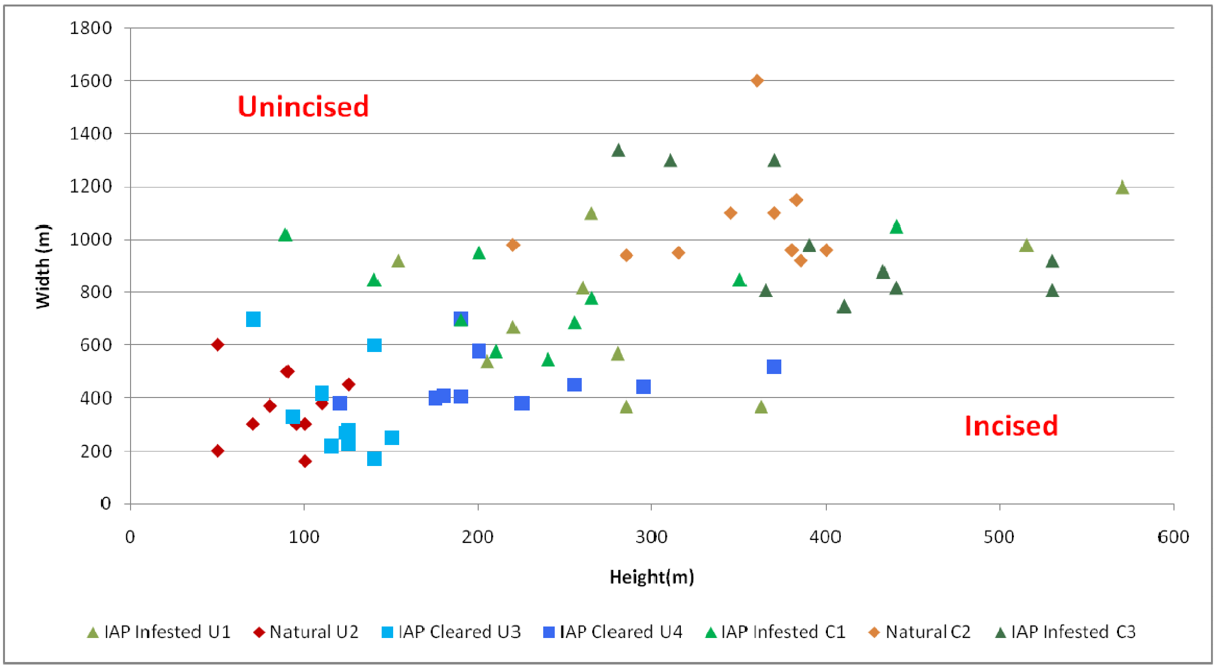

Figure 7.11 Scatter plot of bank height-width relationships at all transects across all sites categorised by degree of infestation

Figure 7.12 forms the same graph as Figure 7.11, but with the point symbols categorised by river bed type. Both alluvial and bedrock river bed types show spread across the graph, indicating little trend between similar river bed types. This again points to local hydrogeomorphological controls, such as valley form, bed gradient (site variables – Figure 3.3) and flow volumes (catchment variables – Figure 3.3), being the dominant determinant of channel dimensions. However, if a line of equal height-width ratios placed on the graph (Figure 7.12) one can see a slight trend that alluvial bed types tend to lie along the line (U4 and C3), while bedrock dominated sites (U2 and C1) broadly cluster more perpendicular to the line. As a result of the scatter plot not showing clear trends, and because of the small number of sites and site repetitions not producing a statistically significant sample size, no further statistical analysis was performed on the MRHS data.

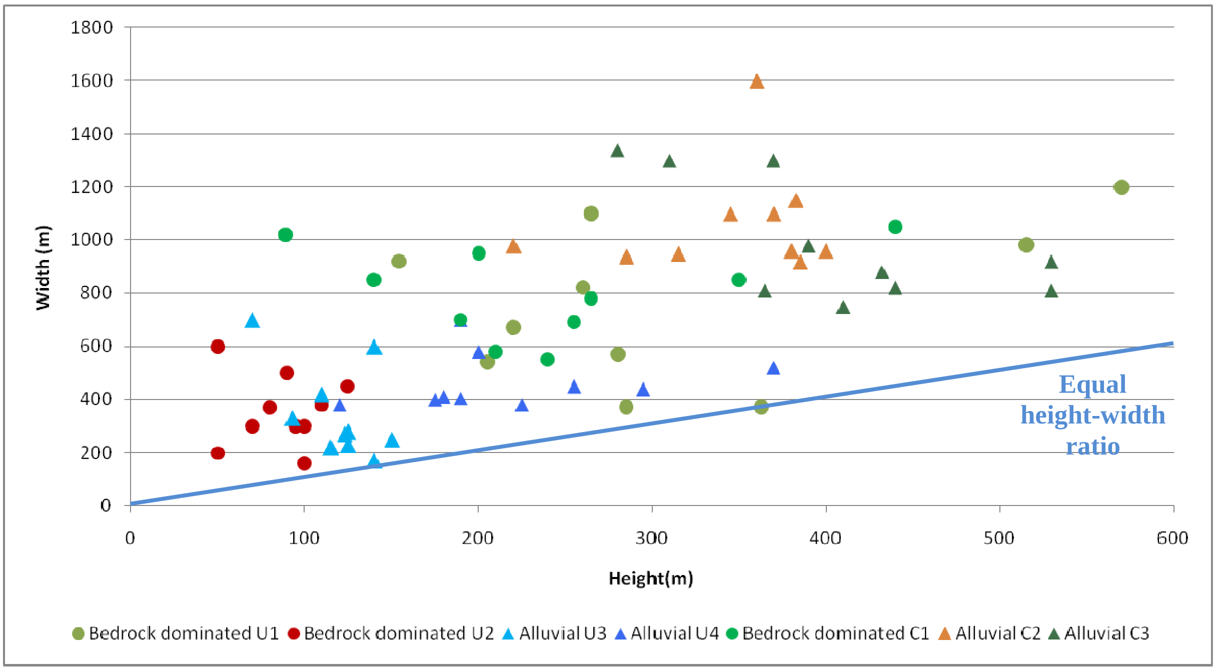

Figure 7.12 Scatter plot of bank height-width relationships at all transects across all sites categorised by river bed type

7.1.6 Analysis of selected MRHS variables relevant to the impacts of IAPs

Table 7.2 shows selected attributes captured by the MRHS forms which are seen as relevant to analysis of the impact of invasion by woody IAPs across the sites. The channel form was reflected as a 'deep incision' at two of the three IAP infested sites and both of the IAP cleared sites. Considering Section I (Appendix 1) of the survey form, which captures the stream bed material, it can be seen that as with the height-width ratio analysis above, there is a stronger relationship between channel incision and the degree of infestation than incision and the alluvial or bedrock dominated nature of the river reach.

The presence of vertical banks that are both undercut and greater in height than 2m, was shown at all of the IAP infested sites. Undercut banks greater than 2m in height were however also present at the natural Site C2. This could be explained by either the presence of invasive *Salix* species or trampling of the riparian banks by livestock, or both, resulting in disturbance of bank groundcover and integrity, allowing erosion and scouring by the stream flow. With regards to Section M. of the survey form, the presence of eroding cliff banks is highest (>33%) at one of the two IAP cleared sites and two of the three IAP infested sites.

Table 7.2 Selected MRHS data relevant to analysing the potential impacts of IAPs

Site area	Site name	Description	Predominant valley form	Predominant channel form	Bed material	Presence of undercut banks	Presence of eroding cliffs	Channel choked with vegetation	Extent of invasion	Features of special interest
MRHS form section			B.	C.	I.	L.	M.	N.	P.	Q.
Umvoti	U1	IAP infested	asymmetrical valley	moderate incision	bedrock	undercut > 2m	present	33 to 67%	continuous IAP cover shading of channel overhanging boughs exposed bankside roots underwater roots IAP's fallen into water	large woody debris debris dams leafy debris in stream loss of groundcover soil erosion dam present upstream
Umvoti	U2	natural	asymmetrical valley	moderate incision	bedrock	none	none	< 33%	Wattle-isolated/scattered	bedrock channel bed
Umvoti	U3	IAP cleared	shallow vee	deep incision	alluvial	undercut 0.5-1m	> 33%	< 33%	occasional clumps semi-continuous	leafy debris in stream presence of wetland soils
Umvoti	U4	IAP cleared	shallow vee	deep incision	alluvial	insignificant	none	33 to 67%	Bugweed-semi continuous shading of channel overhanging boughs exposed bankside roots IAP's fallen into water	large woody debris debris dams leafy debris in stream evidence of IAP clearing
Cedarville	C1	IAP infested	intermediate vee	deep incision	bedrock	undercut > 2m	> 33%	33 to 67%	continuous IAP cover shading of channel overhanging boughs exposed bankside roots underwater roots IAP's fallen into water	large woody debris debris dams leafy debris in stream loss of groundcover soil erosion
Cedarville	C2	natural	shallow/ intermediate vee	moderate incision	alluvial	undercut > 2m	present	< 33%	*Salix* -occasional clumps	presence of *Salix* IAP species
Cedarville	C3	IAP infested	intermediate vee	deep incision	alluvial	undercut > 2m	> 33%	33 to 67%	Wattle-semi continuous shading of channel overhanging boughs underwater roots exposed bankside roots IAP's fallen into water	large woody debris debris dams leafy debris in stream loss of groundcover soil erosion very large boulders

The procedure for Section N (Table 7.2) of the MRHS (Appendix 1) involves estimating the percentage of the study reach which is choked with vegetation, and assigning the reach to one of three percentage classes; <33%, 33-67% and >67% . All of the IAP infested sites and one of the IAP cleared sites fell within the 33-67% choked class. The natural sites and one of the IAP cleared sites reflected less than 33% of the reach being choked with vegetation, showing a strong relationship between the extent of the reach choked and the degree of IAP infestation.

7.1.7 Transect photograph analysis

The methodology of the UK RHS and MRHS dictates taking photographs at each of the ten river transects per survey. Photographs are taken from the transect point upstream, downstream and of both banks. In addition to these transect photographs, photographs are taken of features of special interest across the whole 500m study reach during the river habitat survey. Due to the large number of photographs taken across the total of 70 transects across all the sites included in this study, the photograph analysis was focused on key photographs which illustrate key features and also anomalies. Many additional features and sites were photographed which could not be included in the document.

7.1.7.1 Photograph analysis of the Umvoti sites

Figure 7.13 shows an upstream view of Transect 1 at Umvoti IAP infested Site U1. This site forms the furthest upstream transect at Site U1 (Figure 7.2). Woody debris from *A. mearnsii* can be seen fallen into the channel, with trees growing on the right bank overhanging and

Figure 7.13 Upstream view of transect 1 at IAP infested Site U1

shading the channel. At U1 transect 1 the left bank is characterised by a grass/herbaceous alien plant/broadleaf mix, with the right bank dominated by *A. mearnsii* which is not growing at a sufficient density to completely shade out groundcover. This is in contrast to the right bank of U1 transect 4 further downstream where wattle density has increased and is limiting the streambank groundcover.

Figure 7.14, the right bank of U1 transect 4, is sited within Morphological Map U1-2 (Section 7.2.1 and Figure 7.29). The photograph shows the lack of vegetative groundcover growing on the riparian banks beneath the canopy of wattle. This is in strong contrast to the dense cover of vegetation growing on the banks of the natural Site U2 (Figure 7.16).

Figure 7.14 Lack of bank vegetative groundcover beneath wattle at transect 4 of IAP infested Site U1

In the background of Figure 7.14 a large wattle trunk can be seen which has fallen partially into the channel. As illustrated by Figures 7.13 to 7.15, this was a common occurrence within the 500m reach of IAP infested Site U1. The sites where trunks have fallen completely into the channel frequently result in the accumulation of woody debris, as illustrated in Figure 7.15. The woody debris accumulation at the site shown in Figure 7.15 fills the channel from bank to bank and was observed on site in 2005 and 2009, showing that such blockages are long term features. The stream passing through infested Site U1 did not contain the large volumes of sediment that were present within the stream at infested Site C1, which resulted in damming and a raised bed level upstream of woody debris blockages (Figure 7.20).

Figure 7.15 Woody debris blockage at IAP infested Site U1 dowmstream of transect 5

As shown by Figure 7.16, natural Site U2 shows a strong contrast in condition to the IAP infested Site U1. The riparian banks are densely vegetated, no woody debris is present and undercut, crumbling banks are absent. The bedrock dominated nature of the site can be seen, in addition to the riparian zone and buffer comprised predominantly of grassland. Figures 7.33, 7.35 and 7.37 in Section 7.2.2, which analyses the Morphological Maps produced for natural Site U2, show additional photographs of the stream within the 500m study reach. While the streambanks at U2 transect 5 shown in Figure 7.16 are dominated by grasses with scattered sedges, Figures 7.33, 7.35 and 7.37 show the presence of herbaceous vegetation and small woody shrubs within natural Site U2.

Figure 7.16 Upstream view of transect 5 at natural Site U2

Figure 7.17 illustrates the channel at transect 4 of the Umvoti IAP cleared site U3. The flat topography of the site and absence of macro channel banks is shown by the photograph, which further points toward the site being a channelled wetland (presence of wetland soils – Section 6.2.3).

Figure 7.17 Upstream view of transect 4 at IAP cleared Site U3

7.1.7.2 Photograph analysis of the Cedarville sites

Figure 7.18 shows the left bank at transect 3 of the IAP infested Site C1 near Cedarville. Alien invasive wattle is present at the top of both banks, with the left bank being undercut resulting in scouring of bank material, exposure of tree roots and the progressive collapse of the banktop. The woody debris blockage in the foreground is formed by the collapse of the banktop woody IAPs into the channel, with further woody debris transported from upstream accumulating against the collapsed trees.

Figure 7.18 Left bank of transect 3 at IAP infested Site C1

At some sites (Figure 7.20) the woody debris is sufficiently dense that sediment has accumulated within the debris, creating a dam and upstream pool which soon backfills with sediment, raising the bed of the river and resulting in more regular overtopping of the channel banks. The level of sediment entrained by the stream is illustrated by the brown colour of the stream in Figure 7.18.

Figure 7.19 shows the right bank at transect 5 of the IAP infested site, upstream of transect 3 shown above. The photograph illustrates the impact of dense wattle infestations on the indigenous riparian vegetation. Riparian vegetation has been excluded from the marginal zone and the riparian bank face, with almost no vegetative groundcover present. Beyond the riparian banktop the grassland area has been completely out-competed by the wattle, with the soil being covered only by a mat of wattle seeds and fine leaves. The interface between wattle and grassland at the furthest extent of the invasion appears similar to that shown in Figure 7.21. The channel bank in Figure 7.19 below shows a similar lack of vegetation cover and coverage of wattle leaves and seeds as Figure 7.14 at Umvoti IAP infested Site U1.

Figure 7.19 Right bank at transect 5 of IAP infested Site C1 showing loss of groundcover

Figure 7.20 shows the severity of woody debris blockages that form once a riparian zone has become densely infested by woody IAPs. This particular accumulation of woody debris extends for in excess of 7m downstream. The woody debris slows the stream velocity resulting in the deposition of the high sediment loads resulting from runoff flowing down the poorly vegetated riparian banks beneath the wattle. The debris dams potentially create a higher number of temporary base levels and pools along the profile of the river. The photograph in Figure 7.20 below was taken during winter, with the stream low flows containing a low level of entrained and dissolved sediments. In contrast photographs taken in summer (Figures 7.18 and 7.19) show a high bed load of suspended sediments. The channel in the foreground is almost completely filled with sediment deposited upstream of the debris dam, in contrast to below the debris dam where a deep channel is present.

Figure 7.20 Woody debris blockage at IAP infested Site C1

Figure 7.21 shows the rapid expansion of invasive wattle extending from the riparian zone and advancing further into the surrounding grasslands. This is confirmed in the literature (Richardson and Kluge, 2008), where it has been noted by researchers that *A. mearnsii* species commonly advance into a virgin area along riparian zones, from where the species then expands into the remaining terrestrial areas of the catchment over time (Section 3.3).

Figure 7.21 Advance of invasive *Acacia* out of the riparian zone and into grassland at Site C1

At most long established wattle-grassland interfaces the exclusion of grassland by shading from the dense tree canopy, and hydrophobic soils as a result of the infusion of wattle hydrophobic organic substances, result in a stark contrast in the presence of groundcover as shown in Figure 7.22.

Figure 7.22 The exclusion of grassland growth beneath the invasive wattle canopy at Site C1

Site C2, the Cedarville natural site, shows through Figure 7.23 the increased vegetative cover present at a site which receives little impact from IAPs. A strong increase in the extent of bank vegetative cover can be seen at natural Site C2 when contrasted with a photograph of the Cedarville infested sites shown in Figure 7.19. The sandy nature of the soils at Sites C2 and C3 can be seen in the following three photographs. These soils are particularly sensitive to disturbance of the riparian bank vegetation through trampling by livestock.

Figure 7.23 Transect 3 of natural Site C2 showing typical vegetation structure

Figure 7.24 is a photograph taken facing downstream from transect 9 at IAP infested Site C3. The photograph shows the build up of woody debris which was distributed along sections of the 500m long study reach, which had a lighter IAP infestation than Site C1. Also shown in the photograph is the presence of steep, unvegetated bank faces, which at many transects were being undercut, with chunks of banktop vegetation collapsing into the channel. This is in contrast to the natural Site C2 downstream, shown above, which has a far lower prevalence of steep eroding banks. The lower density of woody invasive plants at Site C3, when compared to infested Site C1 is illustrated by the grassland banktop vegetation structure shown in Figure

7.24. This observation confirms the MRHS, which reflected dominance of grassland within 5m of the banktop at Site C3.

Figure 7.24 Downstream view at transect 9 of IAP infested Site C3

The downstream view of transect 6 shown in Figure 7.25 illustrates the lower density of invasive wattle at Site C3 in comparison to Site C1 (Figures 7.19 and 7.21). The lower density of invasion has allowed grass and other groundcover to grow beneath and between the wattle in many sections. This was highlighted by the MRHS results in Section 7.1.3, which indicated a higher grass cover on the riparian banks at infested Site C3 than infested Site C1. Another observation which distinguishes Site C3 as a more lightly infested site with a shorter infestation history, is the general age of the alien invasive trees which were observed to be older at Site C1 (Figure 7.19).

Figure 7.25 Downstream view at transect 6 of IAP infested Site C3

Figure 7.26 shows one of the more severe woody debris blockages at infested Site C3. The debris dams present at Site C3 were not as large or dense as the debris dams at Site C1 (Figures 7.18 and 7.20), most likely as a result of the lower density of woody infestation within the Site C3 riparian zone (illustrated by aerial photograph Figures 6.13 vs. 6.17 and 7.19 vs. 7.25), contributing less woody debris to the channel. The severe damming and raising of the bed level associated with the severe debris dams at Site C1 were not present at Site C3. This may be explained by the lower density of woody debris, but also the sandy nature of the soils and stream alluvium. The finer silts present at Site C1 are more easily entrained by the majority of flows, where the sandy sediments at Site C1would only be transported during storm events and high flows. The fine silts regularly transported at Site C1 would partly be deposited during the slowing of the flows as the stream flow enters the pools created by the debris dams. The finer sediments would more readily seal the debris dams to the passage of water, creating a further build up of sediment and rise in the stream bed level.

Figure 7.26 Woody debris blockage within the 500m study reach at IAP infested Site C3

7.2 Mapping of Morphological Units and Hydraulic Biotopes

The mapping of morphological units was performed at Umvoti IAP infested Site U1, natural Site U2, and IAP cleared Site U3. Three sections of stream, each of length 20m, were mapped at each site within the 500m study reach of the MRHS and transect cross profiles. Figures 7.2, 7.4 and 7.6 show the locations of the 20m morphological map reaches within the 500m study reaches at Sites U1, U2 and U3.

7.2.1 Umvoti IAP infested Site U1 morphological maps

Morphological Map U1-1 was mapped at the upstream head of the Umvoti IAP infested Site U1. Figure 7.41 is a photograph taken at the upstream end of the 20m mapped reach looking downstream, providing a view of the features mapped within the upstream half of Morphological Map U1-1 (Figure 7.42).

Figure 7.27 Downstream view at site of Morphological Map U1-1

Morphological Map U1-1 (Figure 7.28) shows no strong signs of impact as a result of IAP invasion. The left bank shows good grass cover, with the right bank containing a grass, broadleaf and woody alien invasive mix with limited groundcover beneath the larger woody IAPs. The limited groundcover directly beneath the woody IAPs can be seen in Figure 7.29. The left bank formed a low but vertical 'cliff bank' for approximately 10m of the mapped length as shown by the dashed line in Morphological Map U1-1. This feature is hidden by long grass in Figure 7.27.

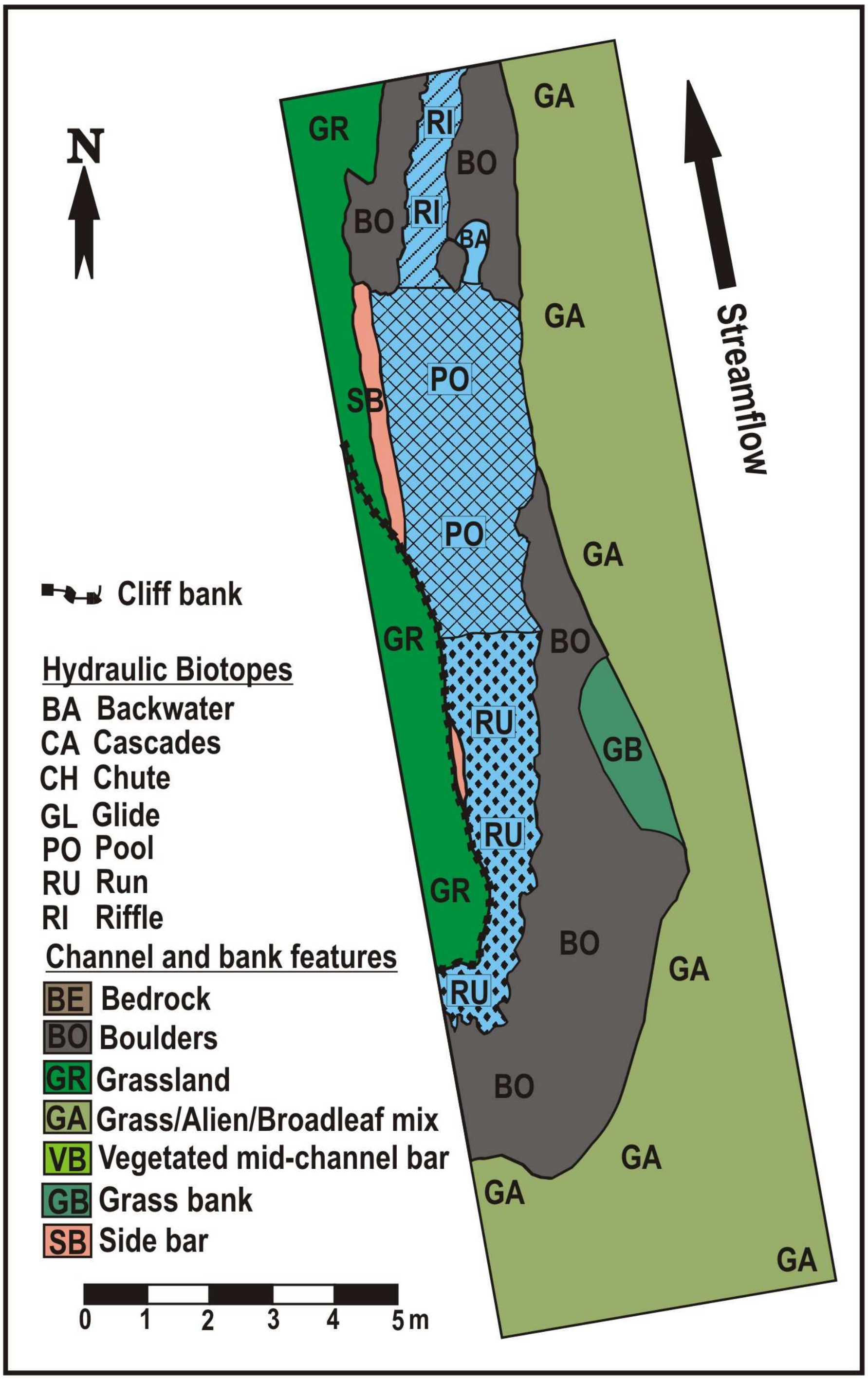

Figure 7.28 Site U1 - Umvoti IAP infested site - Morphological Map U1-1

Further downstream, Morphological Map U1-2 (Figure 7.30) begins to show stronger signs of invasive wattle impact. Figure 7.29 shows the site of Morphological Map U1-2 looking downstream. Signs of woody debris build-up are starting to appear, with the banks under invasive wattle again showing a lack of vegetative groundcover as shown by the insert.

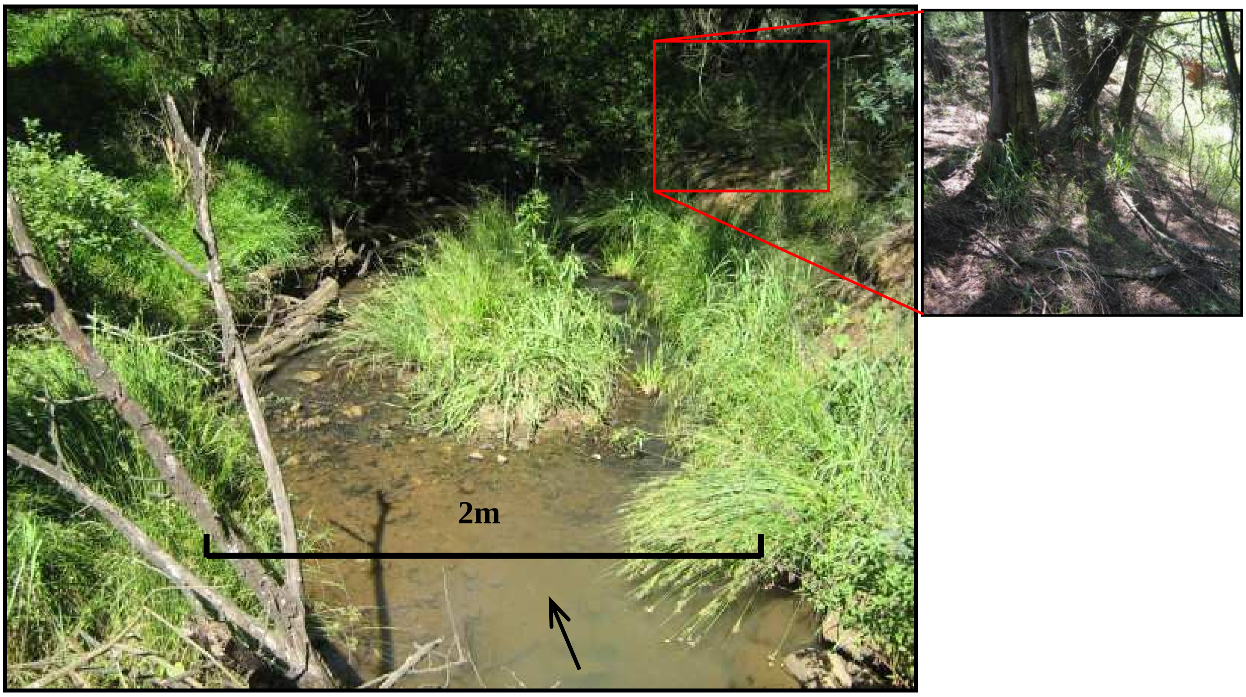

Figure 7.29 Downstream view at site of Morphological Map U1-2

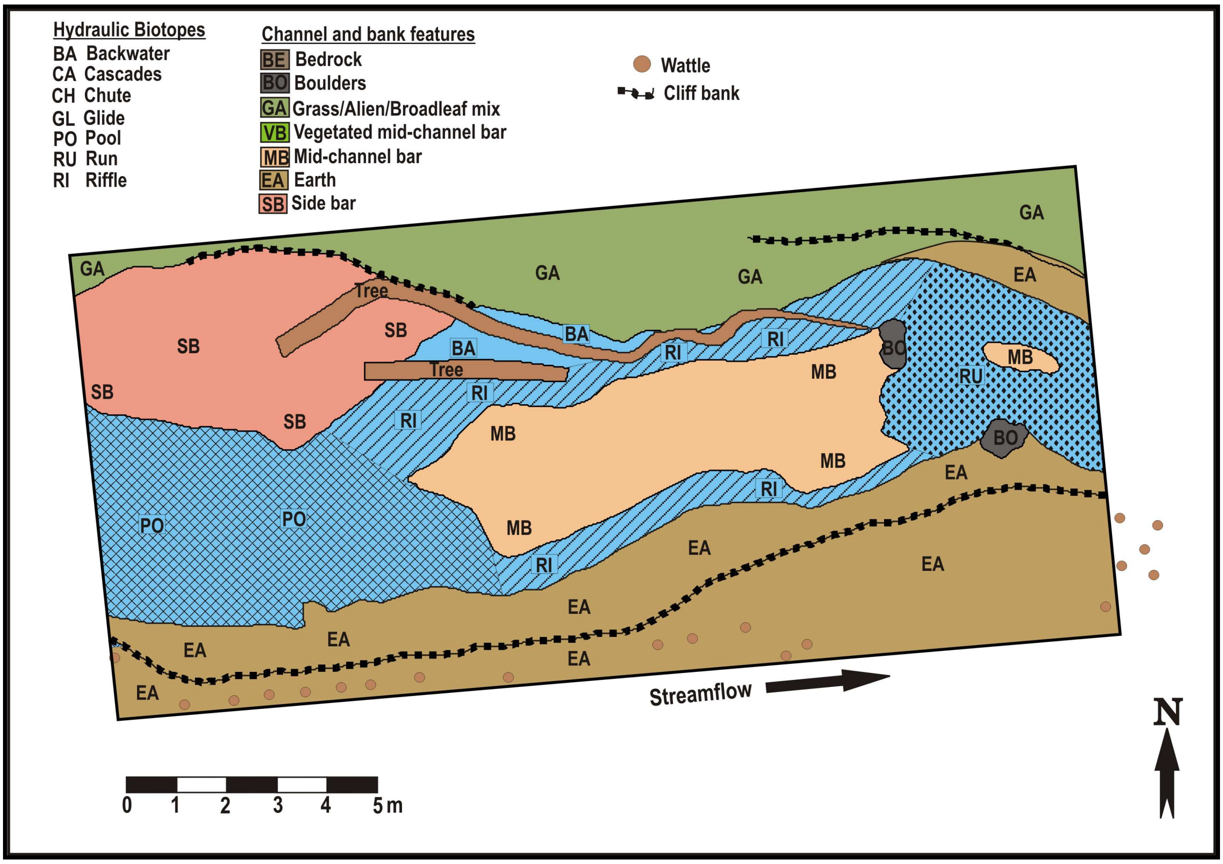

Figure 7.30 Site U1 - Umvoti IAP infested site - Morphological Map U1-2

In Morphological Map U1-2 (Figure 7.30) the right bank is shown composed predominantly of bare earth, illustrating the high rate of vegetative groundcover loss as a result of dense wattle invasion within the riparian zone. An earthy cliff bank with little protective vegetation cover, extends along the right bank for the entire reach. The left bank included a 10m length of cliff bank which was covered at the banktop by a grass, broadleaf and alien mix. Large depositional features in the form of a large sidebar and an unvegetated mid-channel bar may be indicative of accelerated streambank erosion and increased bed loads increasing the rates of alluvial deposition (the mid-channel bar was unvegetated at the time of mapping, with the photograph in Figure 7.29 being taken at a later time). Deposition of stream sediment loads may be accelerated as a result of a slow in the flow rate on encountering woody debris deposits, such as the fallen wattle trunks at this site, and woody debris accumulations immediately downstream.

Further downstream within the IAP infested reach Figure 7.31 shows the start of the woody debris accumulation within the site of Morphological Map U1-3, which is also shown in Figure 7.15. The grass/alien/broadleaf mix can be seen on the left bank, with wattle from the right bank seen overhanging into the channel. Morphological Map U1-3 (Figure 7.32) shows similar characteristics with regards to the condition of the streambanks as Map U1-2. The right bank is completely void of any groundcover, and takes the form of a cliff bank for the entire 20m reach. One difference from morphological Map U1-2 is that, at the flow levels present during mapping, the cliff bank forms the marginal zone of the river channel, and is in direct contact with the streamflow. As a result the bank is severely undercut, with exposed tree roots extending into the channel from the wattle growing within the riparian zone. Morphological Map U1-3 indicates again the presence of a large unvegetated side bar, showing recent sediment deposition. A large, dense accumulation of woody debris is shown present in the lower section of the mapped reach. Within the main flow section of the channel against the right bank, a chute is present immediately upstream of the debris, with a run present within a section of the debris accumulation.

The presence of these faster flowing flow types shows that along this section finer debris and sediment has not accumulated within the debris to a sufficient density to slow flows significantly. However on the left of the channel sections of backwater are present indicating no flow through the debris.

Figure 7.31 Downstream view at site of Morphological Map U1-3

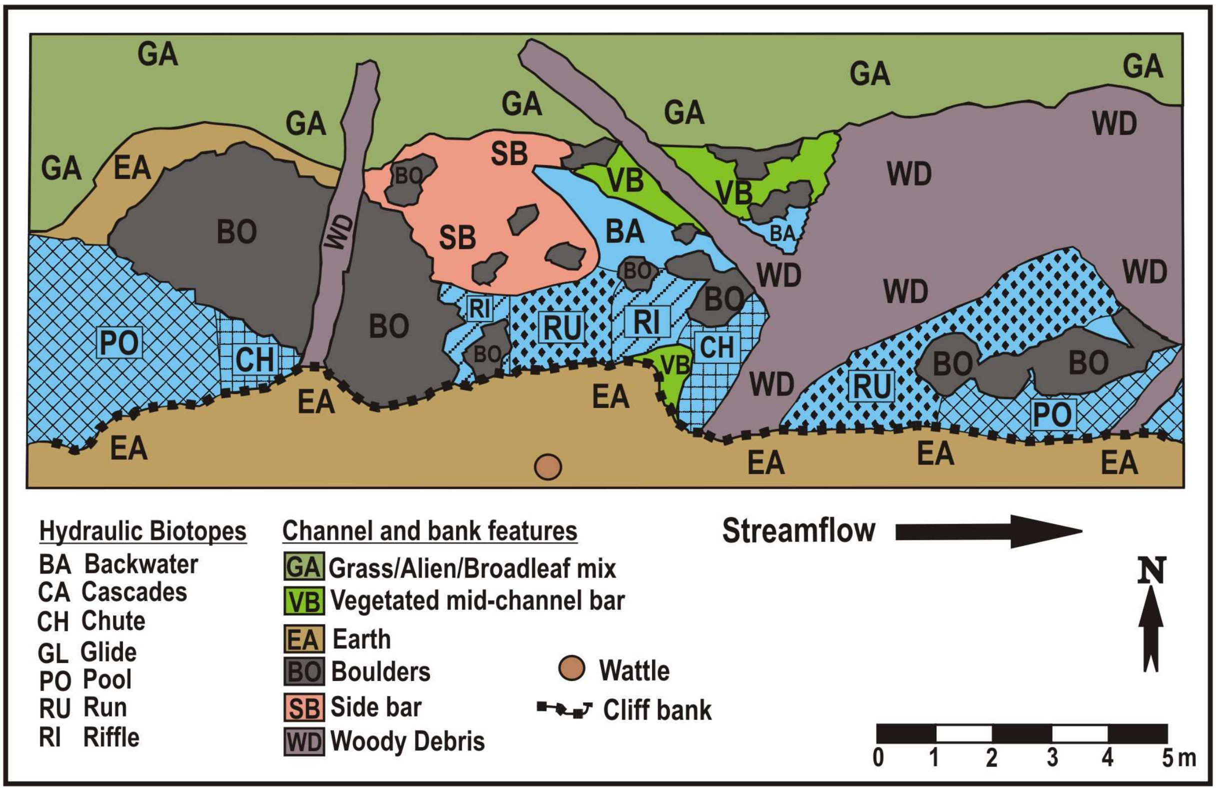

Figure 7.32 Site U1 - Umvoti IAP infested site - Morphological Map U1-3

The presence of a large vegetated bar against the left bank shows that accumulated sediments were not regularly shifted by flowing water, allowing vegetation colonisation. These features all indicate that the debris dam is confining flow to a narrow and rapidly flowing chute against the right bank, increasing bank scour, undercutting and instability. In addition, were this chute to become blocked by finer debris and then sediments, the debris mass would become a debris dam, potentially flooding waters out of the channel and onto the adjacent riparian flood plain (Figure 2.1).

7.2.2 Umvoti natural Site U2 morphological maps

At the Umvoti natural Site C2 the Morphological Map U2-1 (Figure 7.34) shows good grass cover within the riparian zone, and an absence of bare earth and cliff banks. This is confirmed by Figure 7.33, which shows an upstream view along the 20m reach. The presence of large bedrock outcrops shows the stream bed to be dominated by bedrock and boulders. In terms of flow types the glide at the head of the 20m reach illustrates shallow, unconstricted and smooth flow over bedrock. The remainder of the flow types take the form of natural pool and run sequences with a chute present where boulder and bedrock outcrops have constricted flow and produced a drop in the base level of the stream bed downstream.

Figure 7.33 Upstream view at the site of Morphological Map U2-1

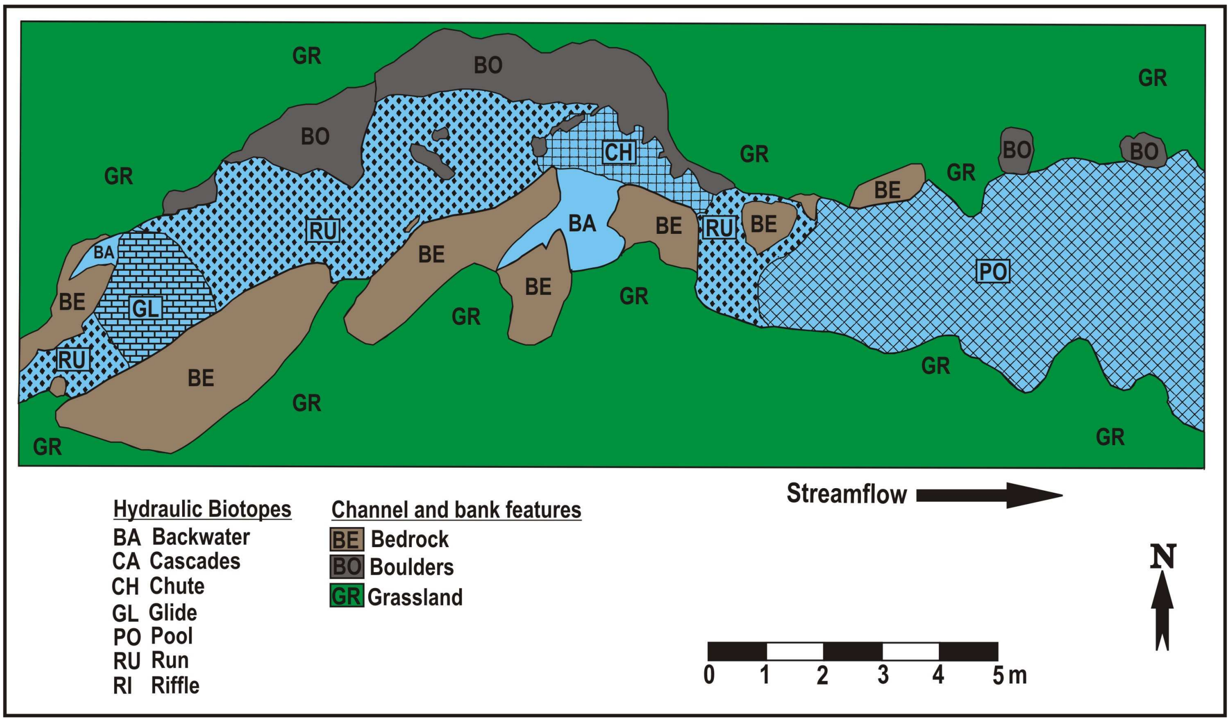

Figure 7.34 Site U2 - Umvoti natural site - Morphological Map U2-1

Morphological Map U2-2 in Figure 7.36, shows similar features to map U2-1, with the only major difference being the presence of a small vegetated bar and a cascade sequence. The cascade is produced in response to a drop in stream bed level and flow constriction associated with a large bedrock outcrop, which can bee seen at the upstream end of the Morphological Map. This feature can be seen in the background of the site photograph in Figure 7.35 below.

Figure 7.35 Upstream view at the site of Morphological Map U2-2

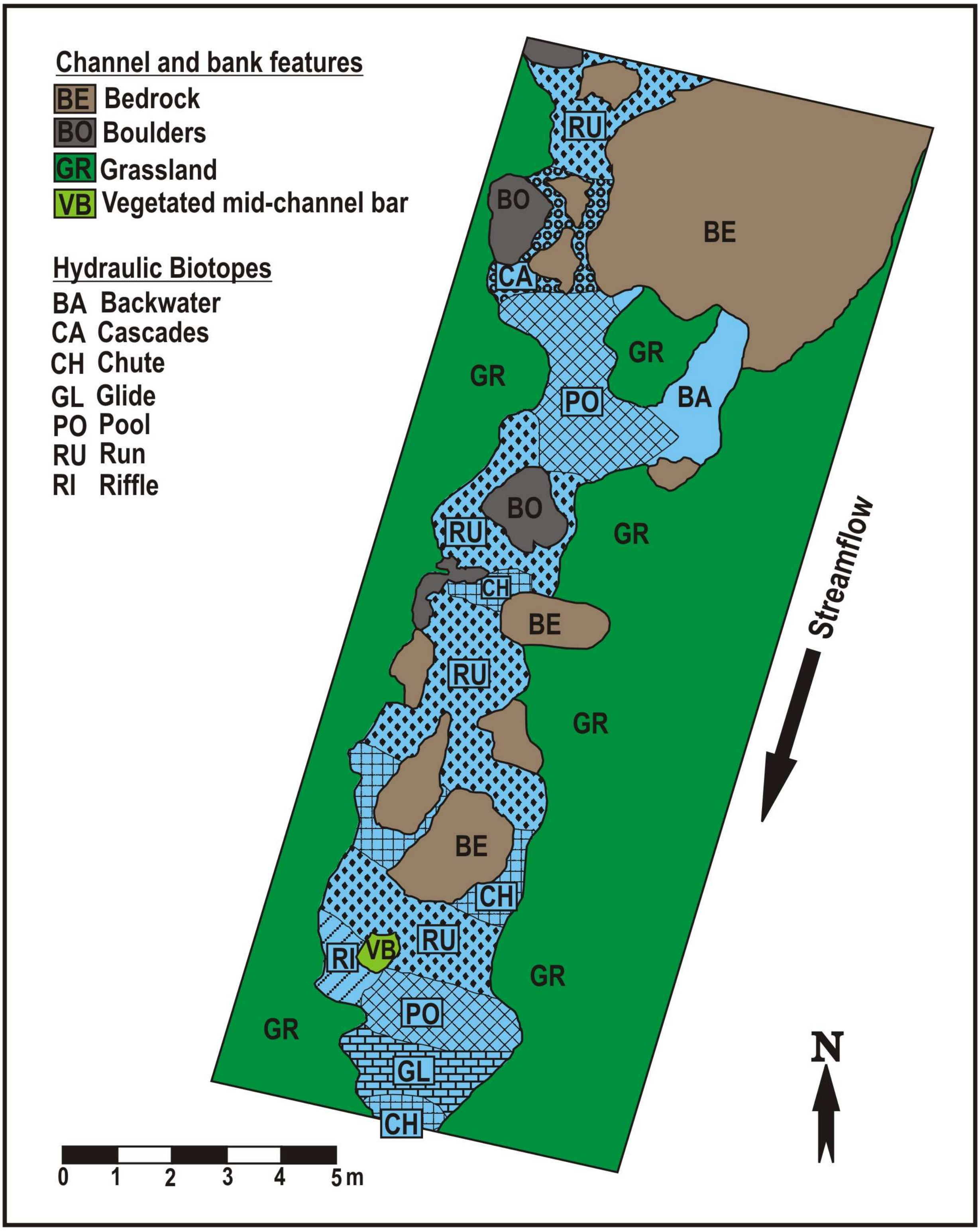

Figure 7.36 Site U2 - Umvoti natural site - Morphological Map U2-2

Figures 7.37 and 7.38 at Morphological Map U2-3 again show well vegetated banks, with the presence of bedrock outcrops. Only one channel bar was present within this 20m reach, and was vegetated.

Figure 7.37 Upstream view at the site of Morphological Map U2-3

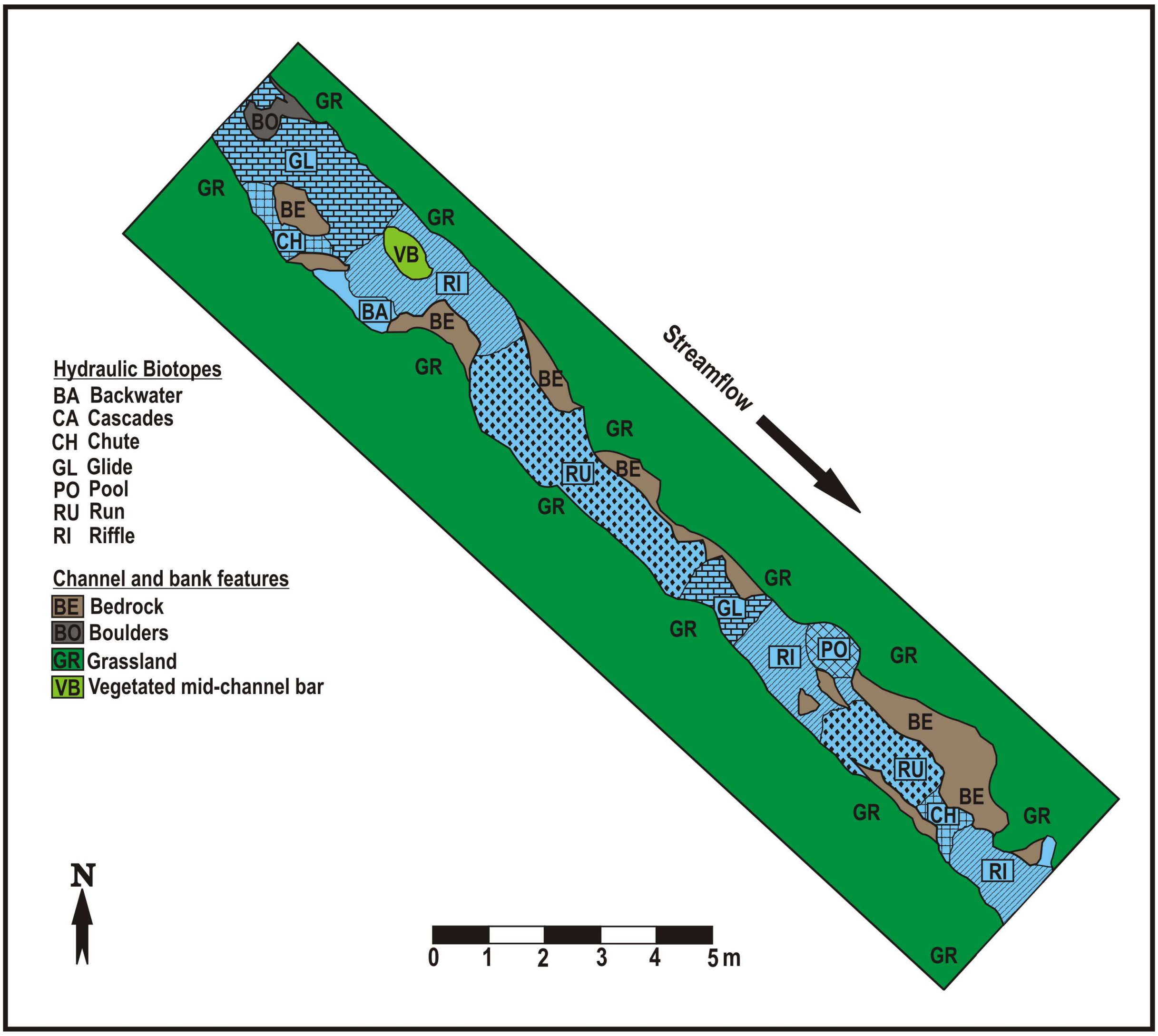

Figure 7.38 Site U2 - Umvoti natural site - Morphological Map U2-3

All three morphological maps for Site U2 show a complete absence of unvegetated sand bars, with only a limited number of vegetated bars being present. This finding might be explained by the well vegetated riparian zones, with little erosion and sediment contribution to the watercourse. This is in strong contrast to the large amounts of sediments shown moving through the IAP infested sites in Morphological Maps U1-2 and U1-3, and the increased number of channel bars.

7.2.3 Umvoti IAP cleared Site U3 morphological maps

The morphological Maps U3-1 to U3-3 appear to show no major impact as a result of previous infestation by invasive alien plants. Riparian and streambank vegetation grows dense with no bare earth present within any of the Morphological Maps of the site (Figures 7.40, 7.42 and 7.44). The presence of strong meandering in the channel form (particularly Morphological Map in U3-1 in Figure 7.40) is an indication of the flat relief of the site, with the riparian plain adjacent to the channel indicating the presence of wetland soils during field sampling (Section 6.2.3). Figure 7.39 shows an upstream view of Morphological Map U3-1, visually illustrating the narrow channel which meanders through the site.

Figure 7.39 Upstream view at the site of Morphological Map U3-1

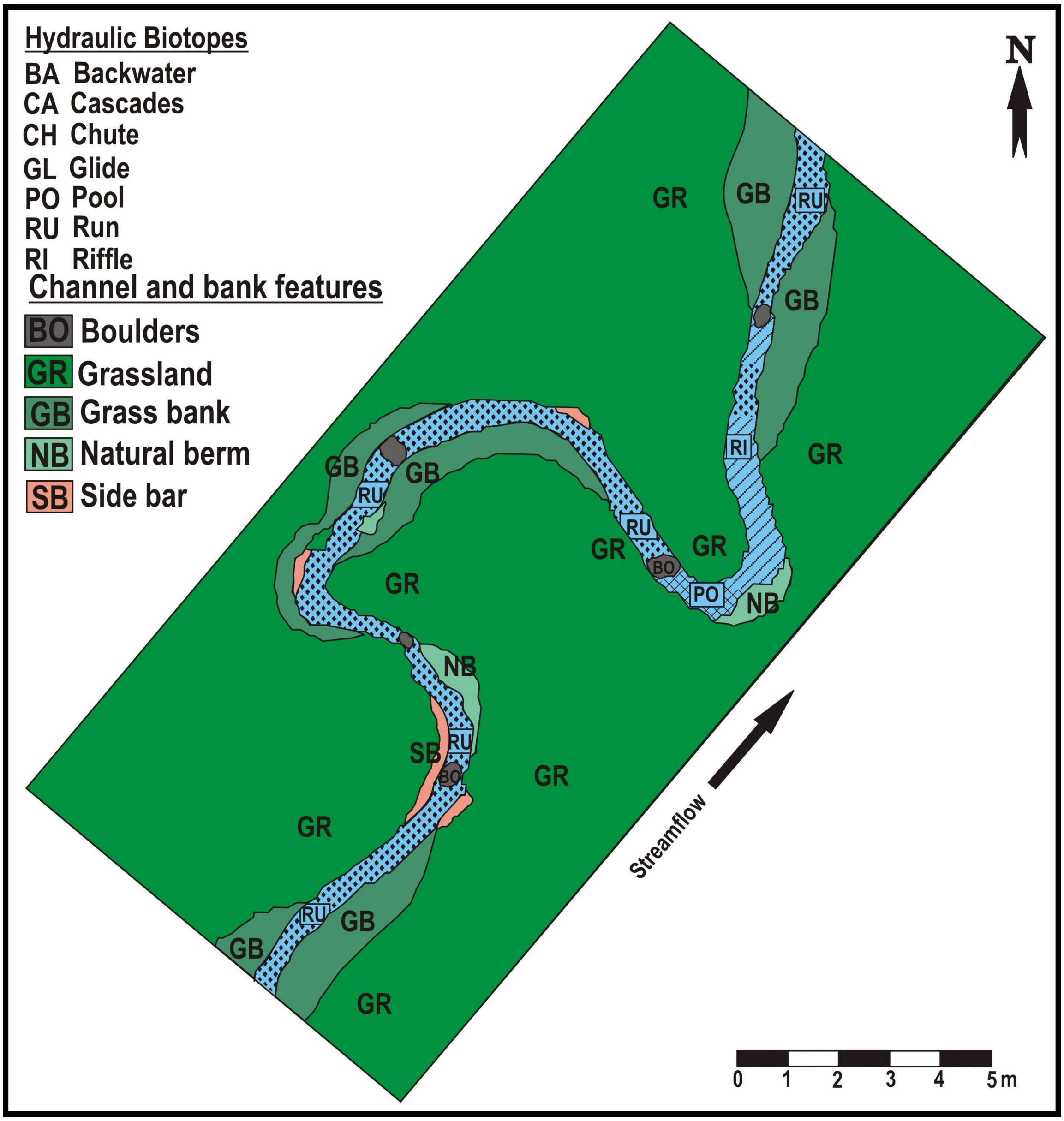

Figure 7.40 Site U3 - Umvoti IAP cleared site - Morphological Map U3-1

Similarly to natural Site U2, very few channel bar features are present, indicating that limited amounts of alluvial sediments pass through the site. While the stream at Site U3 is smaller than that at Sites U1 and U2, the lower sediment load could also be explained by the well vegetated channel banks.

Figure 7.41 Upstream view at the site of Morphological Map U3-2

No Bedrock outcrops are present at Site U3, however boulders and pebble beds are present at selected sections of the site. Figure 7.41 includes a view of a pebble bed which is mapped and grouped under boulders within Morphological Map U3-2 (Figure 7.42). The pebble bed is associated with a riffle sequence as illustrated in Morphological Map U3-2 (Figure 7.42).

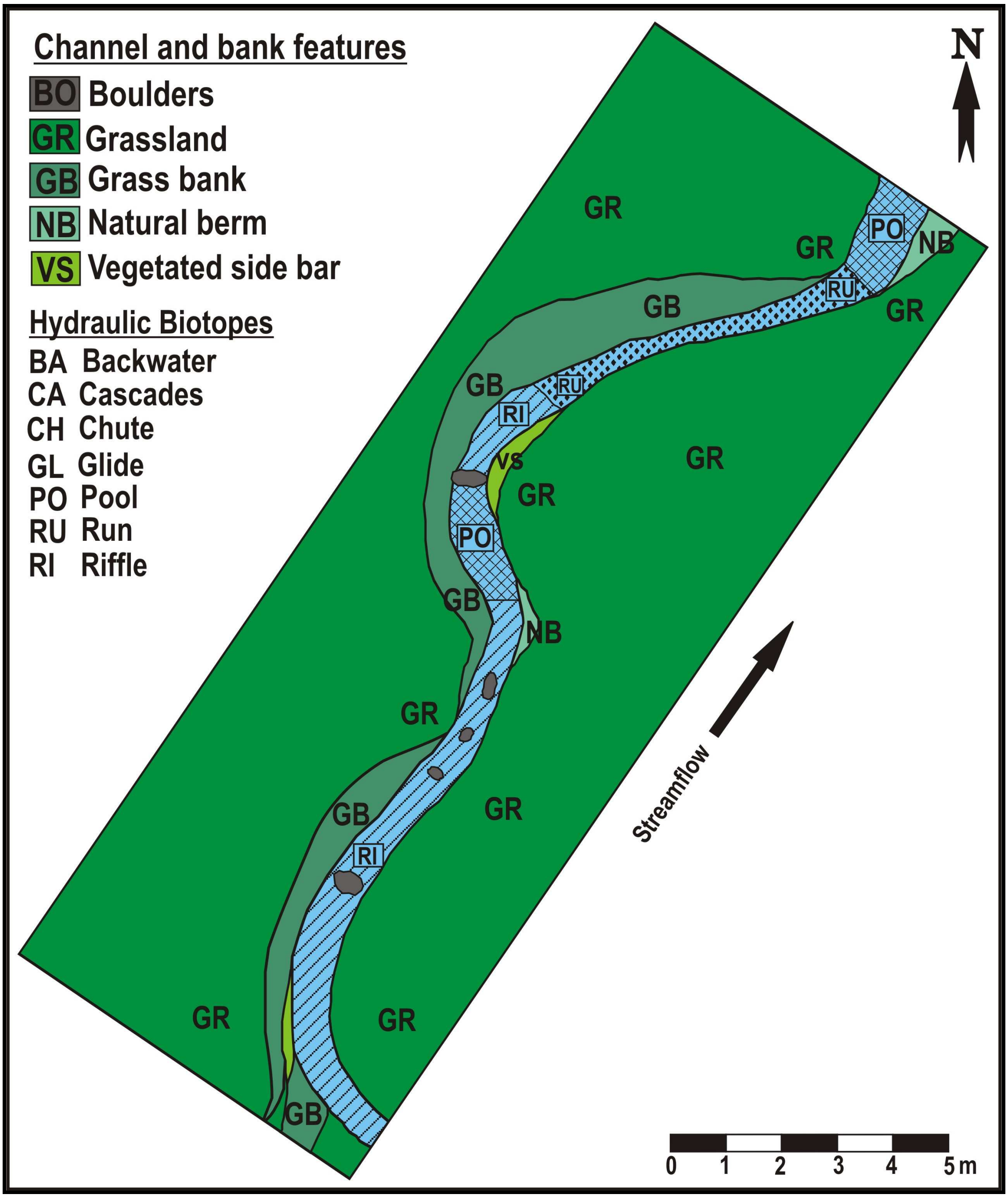

Figure 7.42 Site U3 - Umvoti IAP cleared site - Morphological Map U3-2

In contrast to the site photographs of the natural site U2 (Figures 7.33, 7.35 and 7.37), the photographs of IAP cleared Site U3 (Figures 7.39, 7.41 and 7.43) show a dominance of grassland within the riparian zone with very low presence of reeds, herbaceous vegetation and woody shrubs. This could be as a result of the site not being a typical riparian channel with associated features, such as riparian banks and a channel shelf (Figure 2.1), but rather that the site was formerly an un-channelled wetland which developed an incised channel through man-made activity or erosion.

Figure 7.43 Upstream view at the site of Morphological Map U3-3

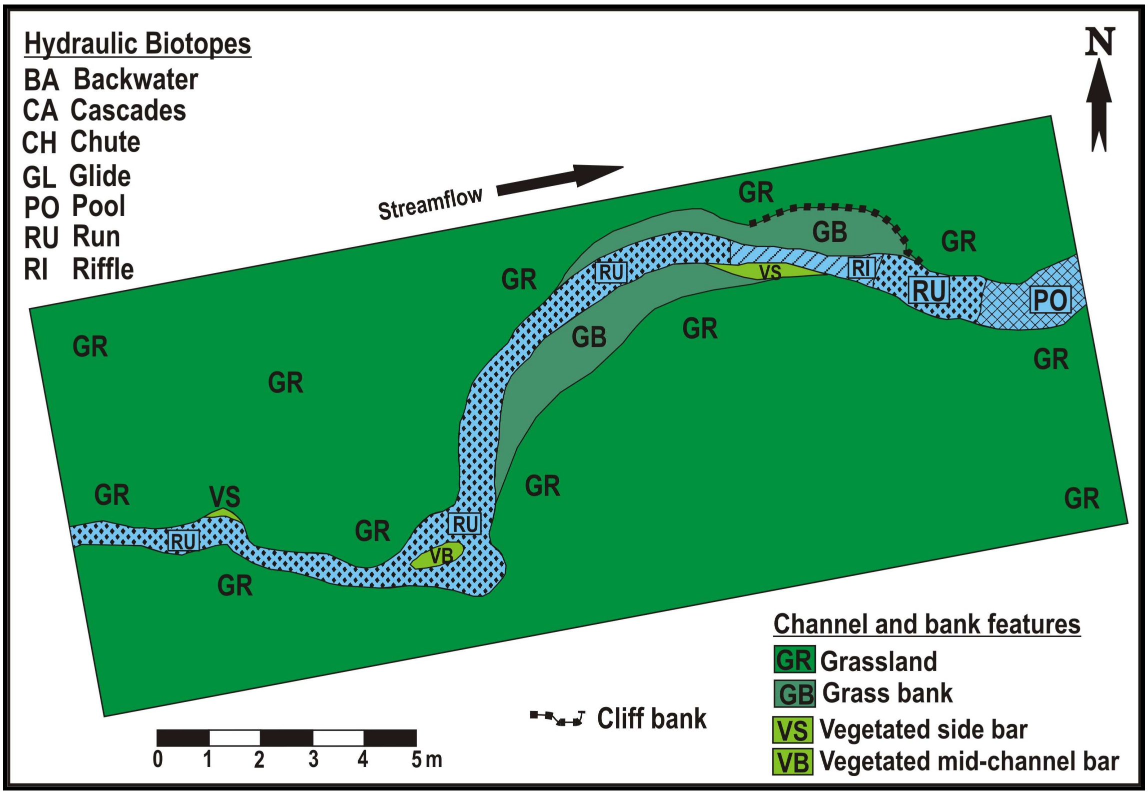

Figure 7.44 Site U3 - Umvoti IAP cleared site - Morphological Map U3-3

7.3 Channel Cross Profile Analysis

With respect to capturing of the cross profiles, the mapping grade GPS was found to be accurate at the natural and IAP cleared sites, however at the infested sites obtaining strong satellite signals proved problematic. Within the undergrowth of the IAP infested sites the altitude reading of the GPS was found to be erratic. However, if these spikes and troughs in the altitude readings were removed, the profile produced still showed the general cross section form of the channel and riparian zone. As a result the altitude data outliers within the infested cross profiles were manually deleted, creating cross profiles for the infested sites which, while not as accurate as the cleared and natural sites, still give sufficient insight into the dominant channel form. Thus, errors and outliers were manually identified and removed from the cross profiles at sites C1, C3 and U1, the three IAP infested sites.

Cross profiles were taken at all 10 transects at sites U1, U2 and C1, C2 and C3. Cross profiles were not taken at Umvoti IAP cleared Site U3 as the site has very flat topography, no macro channel and a small flow channel of average 1.1m depth, which would not yield a cross profile of any significance. Due to the high number of cross profiles produced, two representative profiles from each site were selected for display in Section 7.3 (Figures 7.45 to 7.54).

7.3.1 Cedarville sites channel cross profile analysis

From a visual assessment of the Cedarville site cross profiles (Figures 7.45 to 7.50) natural Site C2 appears to have a narrower channel width in relation to channel depth than IAP infested Site C3. This is of particular importance as Sites C2 (natural) and C3 (IAP infested) fall on the same river (Figure 6.3) with the result that variables related to the influence of geological controls and dominant valley morphology on channel form are removed. This contrasts with the findings of the channel dimension data gathered by the MRHS (Section 7.1.5), where the average height-width ratio reflects natural Site C2 to be wider in relation to channel height, than IAP infested Site C3.

From the cross profiles IAP infested site C1 transect 4 appears wider, showing correlation with the IAP infested C3 transects, with C1 transect 8 being narrower and corresponding closer to the widths of the natural Site C2 transects. This lack of relationship could be due to local variability within the 500m study reach , or due to GPS errors under the dense canopy at Site C1. IAP infested Site C3 was less densely infested resulting in more accurate GPS readings.

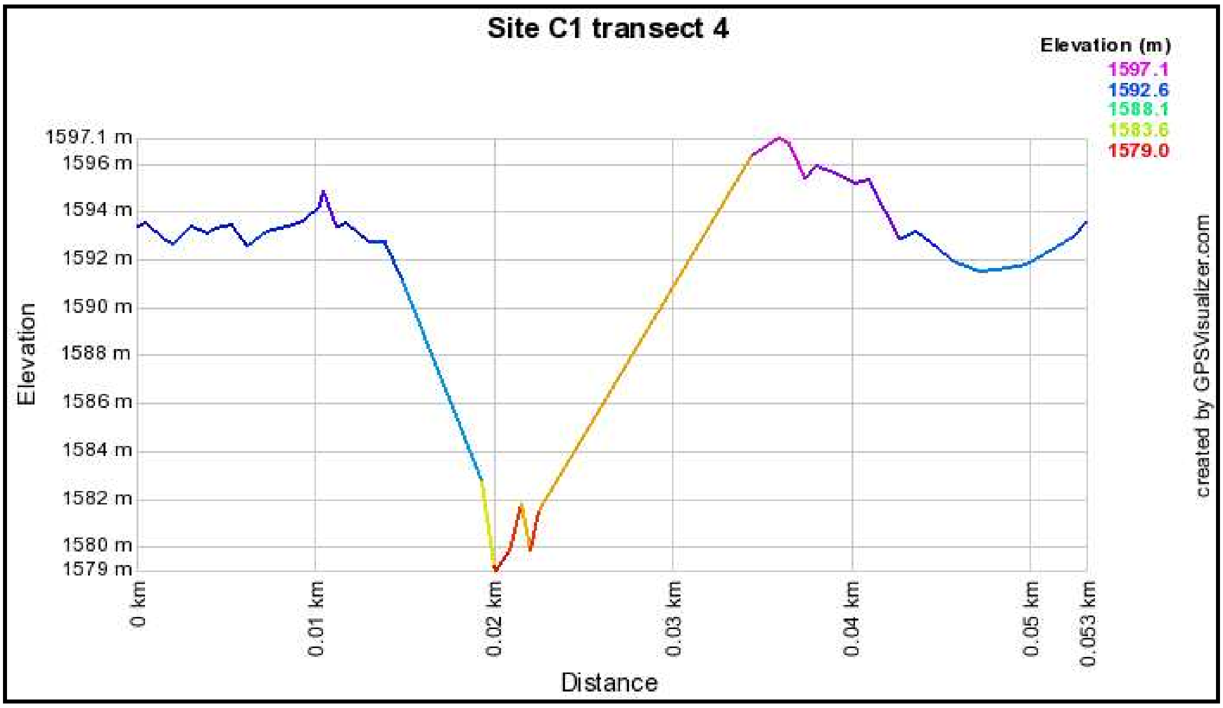

Figure 7.45 Site C1 - Cross profile for IAP infested site at transect 4

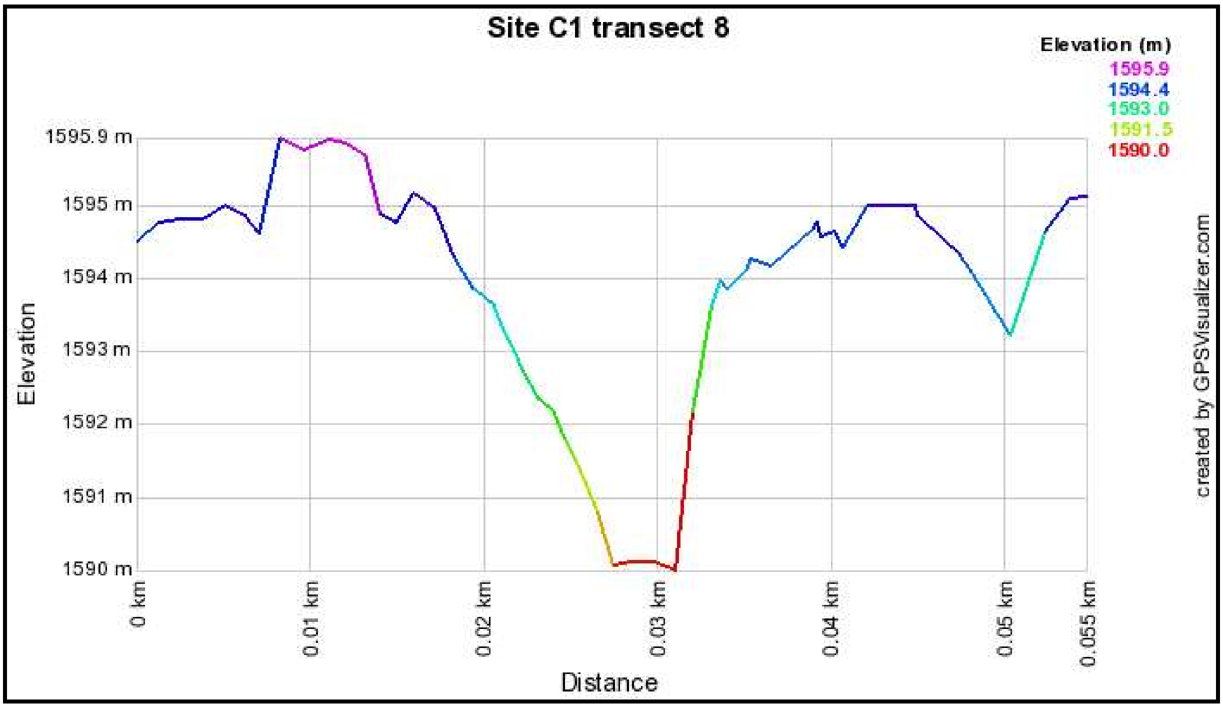

Figure 7.46 Site C1 - Cross profile for IAP infested site at transect 8

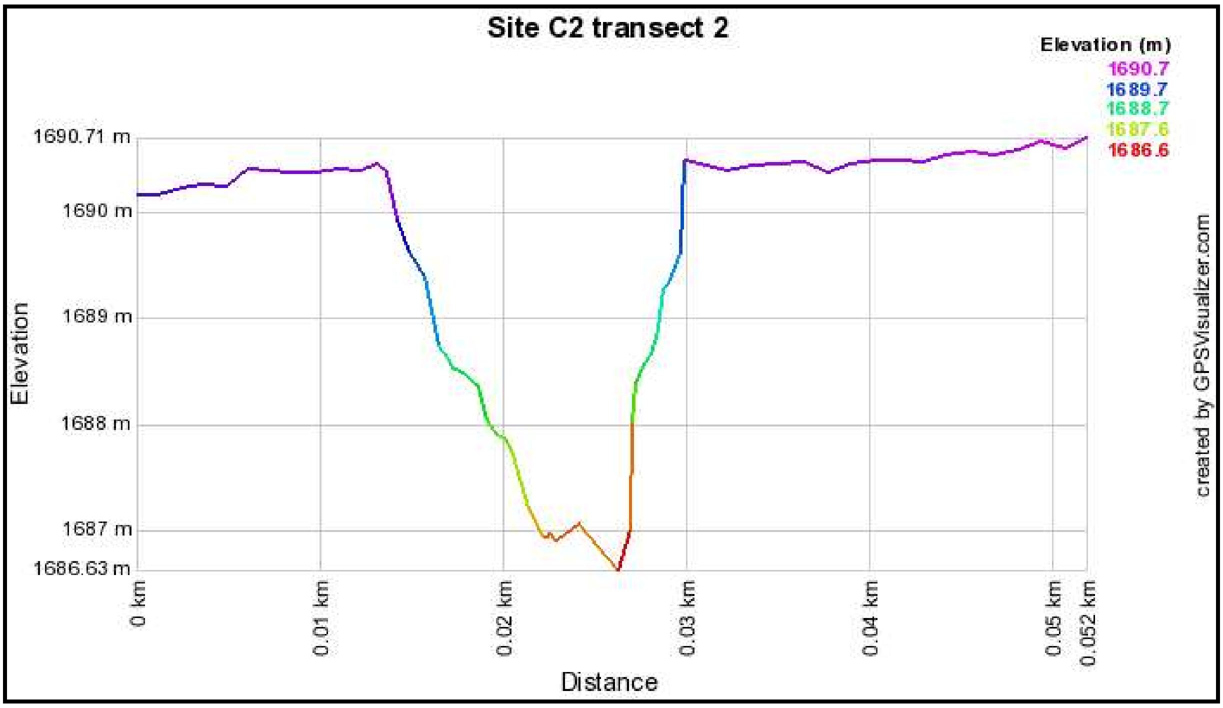

Figure 7.47 Site C2 - Cross profile for natural site at transect 2

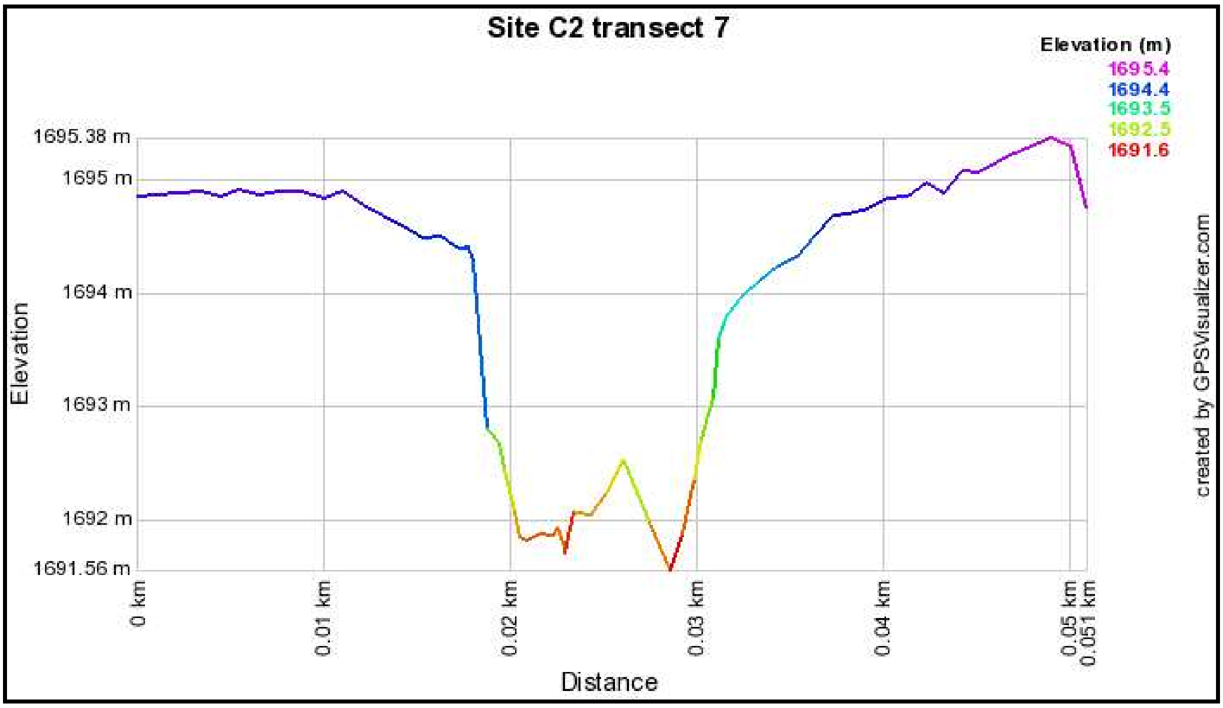

Figure 7.48 Site C2 - Cross profile for natural site at transect 7

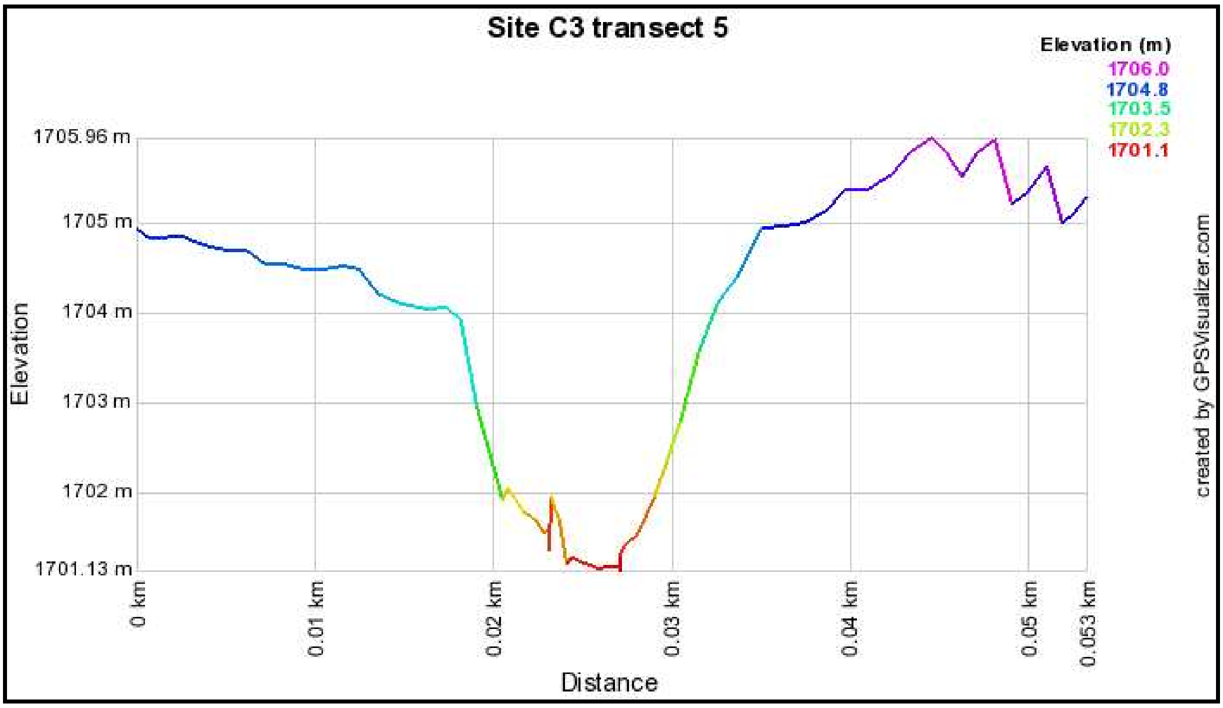

Figure 7.49 Site C3 - Cross profile for IAP infested site at transect 5

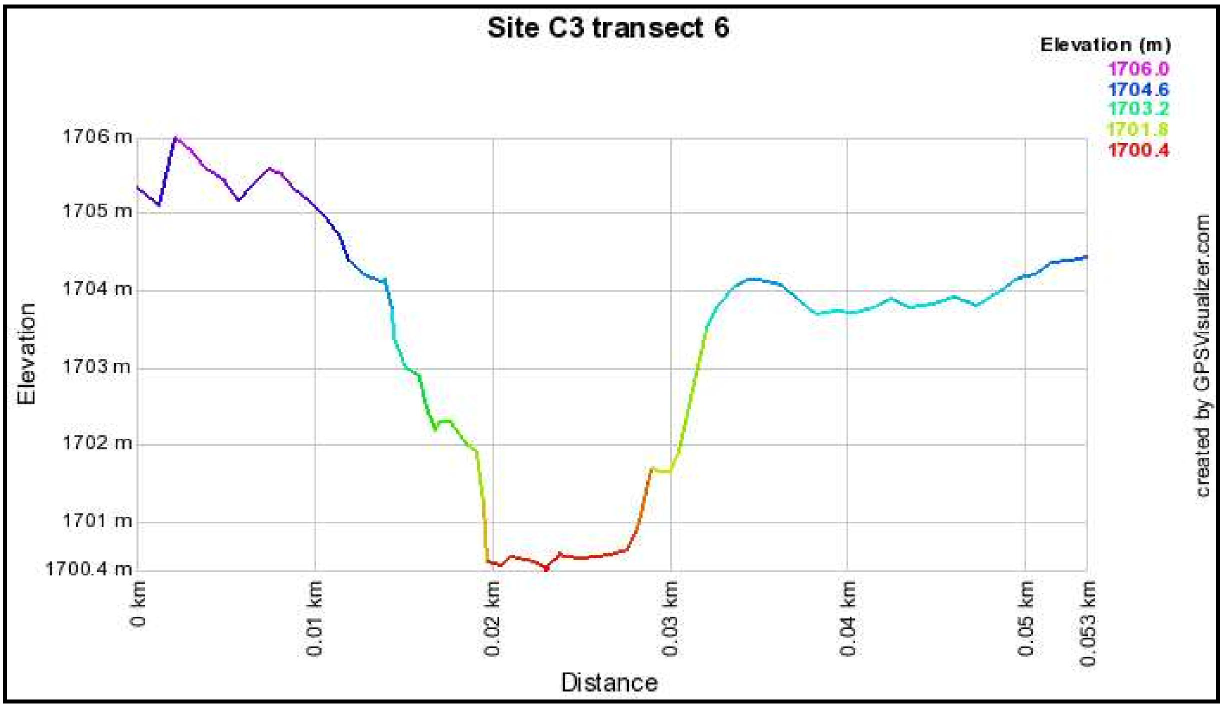

Figure 7.50 Site C3 - Cross profile for IAP infested site at transect 6

7.3.2 Umvoti sites channel cross profile analysis

IAP infested Site U1 forms an asymmetrical valley (Section 6.2.1) with a steep left bank and flatter valley side extending from the right banktop. This asymmetry is reflected in the cross profiles captured by the GPS (Figures 7.51 and 7.52). Similarly, natural Site U2 is comprised of asymmetrical valley sections consisting of interlocking spurs cut by a curving channel (Figures 7.3 and 7.4). As a result U2 transects 5 and 7 reflect the asymmetrical valley faces on opposite sides.

No strong relationships can be seen across the profiles at the Umvoti sites and between the Umvoti sites and the Cedarville sites. Part of the reason for this could be that the channels were not as incised and sharply defined within the valley form as was the case at the Cedarville sites. The overall valley form of the Umvoti sites dominates the cross profile, with the channel form lost in the scale. This can be seen in Figure 7.30 where the photograph of natural Site U2 transect 5 shows a poorly defined channel in comparison to natural Site C2 transect 3 in Figure 7.37.

However, focusing on just the red portions of the Umvoti cross profiles (Figures 7.51 to 7.54), which form the flow channels, it appears that the channel form at the U1 IAP infested sites is wider and shallower when compared to the U2 natural sites. This contrasts with the findings of the channel dimension data gathered by the MRHS (Section 7.1.5), where the average height-width ratio reflects IAP infested Site U1 to be narrower in relation to channel height, than natural Site U2.

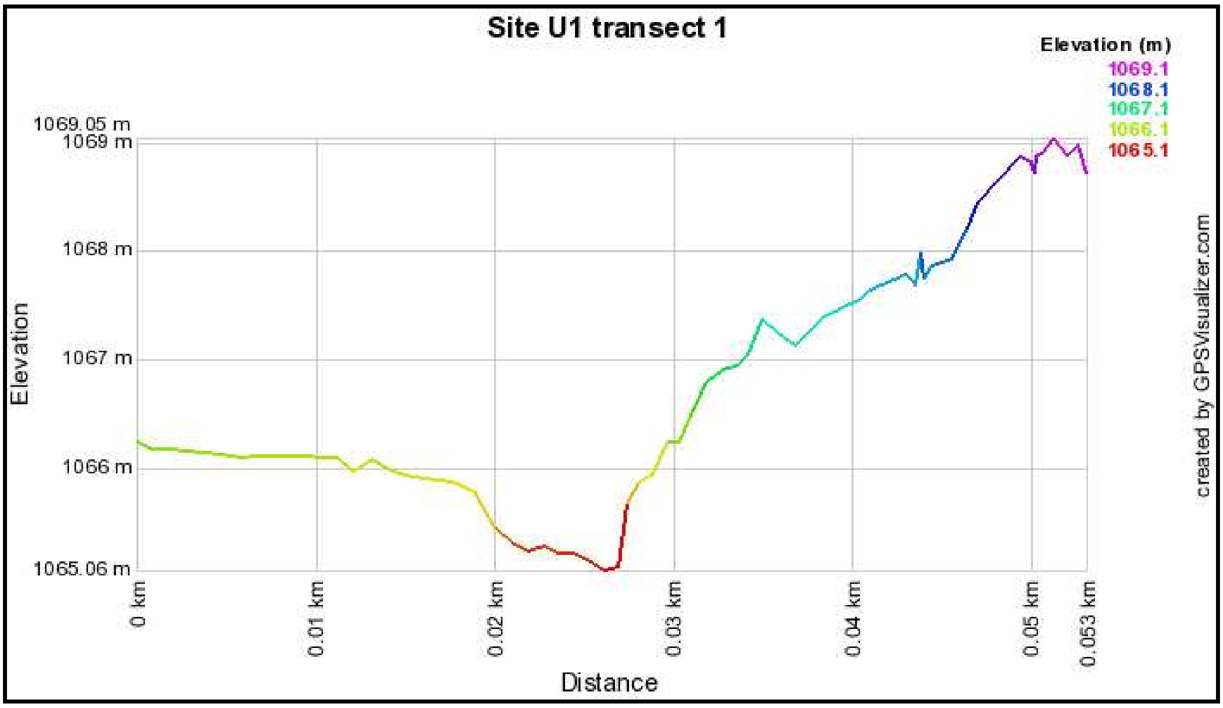

Figure 7.51 Site U1 - Cross profile for IAP infested site at transect 1

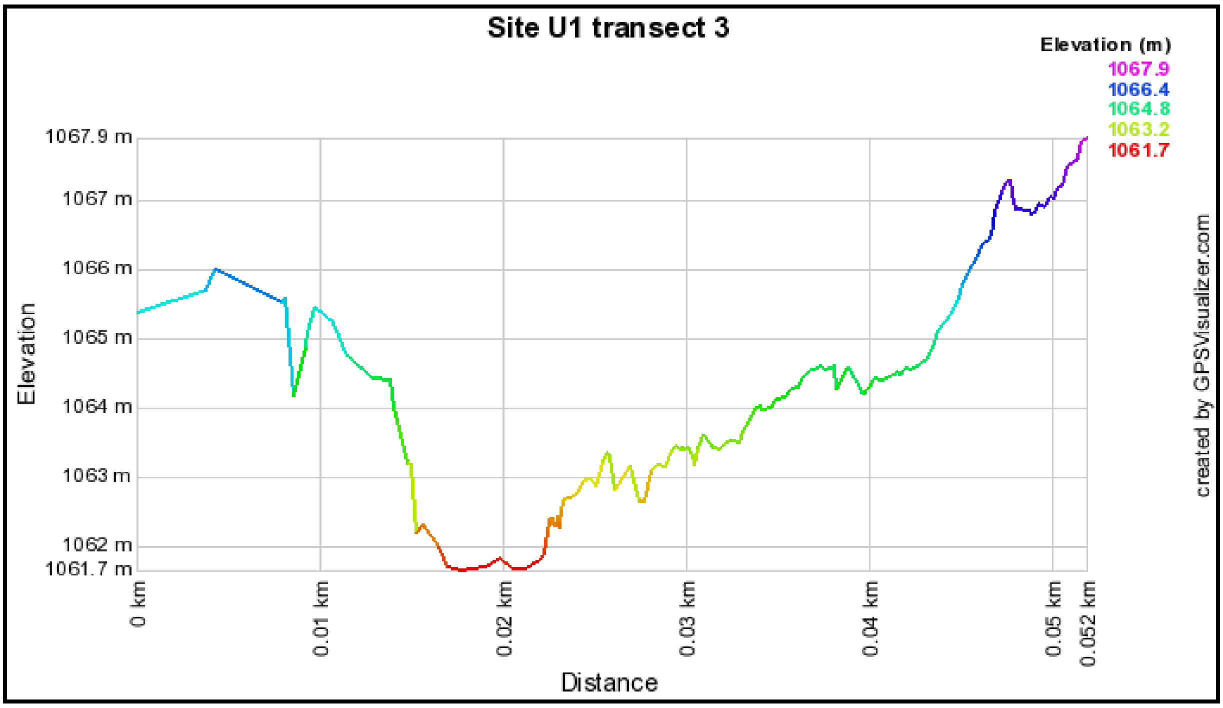

Figure 7.52 Site U1 - Cross profile for IAP infested site at transect 3

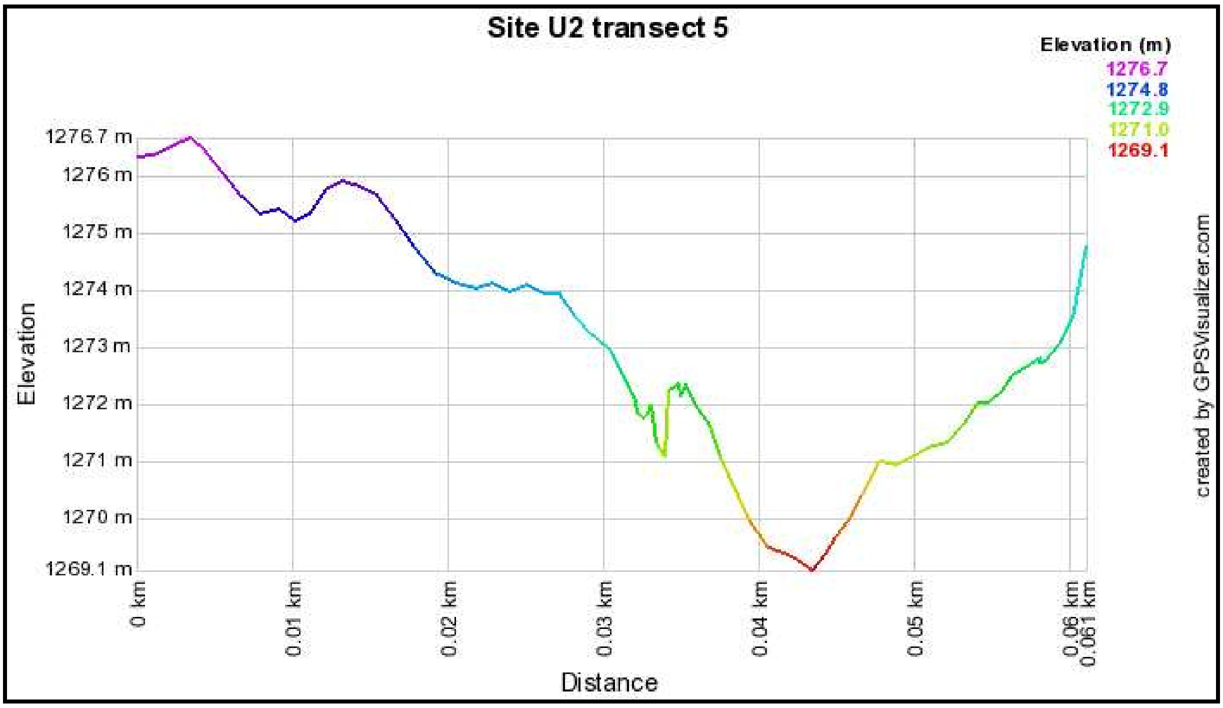

Figure 7.53 Site U2 - Cross profile for natural site at transect 5

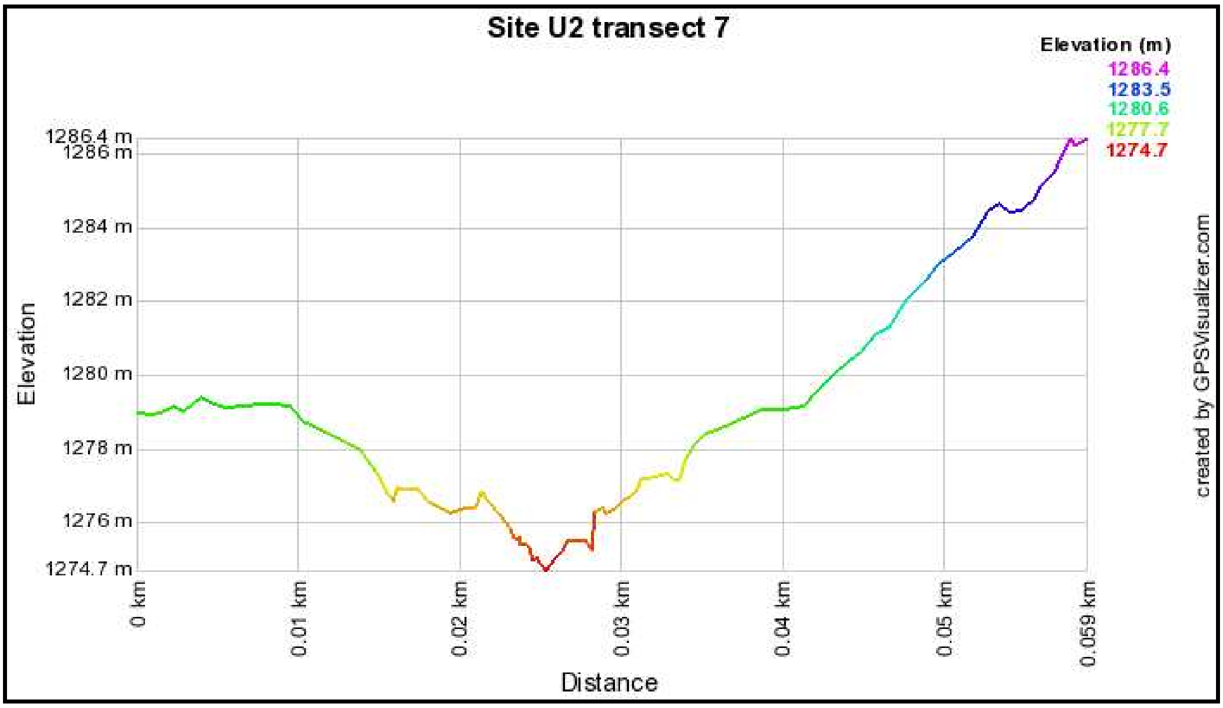

Figure 7.54 Site U2 - Cross profile for natural site at transect 7

8. DISCUSSION

Current scientific literature on the role of indigenous riparian vegetation in maintaining streambank stability and shaping stream morphology, as well as the effects of IAPs on indigenous vegetation, groundcover and soils, shows that invasion by alien species can significantly interfere with fluvial and riparian processes (Section 3.2). Literature addressing the dynamic relationship between channel morphology and vegetation growth gives evidence that riparian vegetation can play a key role in determining channel morphology and streambank stability. Streambank and marginal zone vegetation is shown to have a strong influence on the balance between bank scour and deposition. Woody IAPs commonly result in increased scour due to a lack of bank vegetative groundcover, with woody roots and stems interfering with flow and creating turbulence. The introduction of woody IAPs also interferes with the mass stability of river banks, where rooting depths shallower than bank height have the potential to increase bank instability (Section 4.2 and Figure 4.1). Field observations reported in the literature reflect that low order, headwater channels which become densely vegetated with woody species tend to widen, while high order rivers under similar conditions tend to develop narrower, deeper channels (Section 4.3). No correlation could be seen between stream order and the degree of incision of the channels across the sites (Figure 7.10). The extent of impact on channel form and bank stability will depend on the nature of the hydrogeomorphic environment, the species and the density of woody IAP.

Interference through IAP invasion with the natural physical processes and ecological systems operating within riparian zones can result in severe alteration and degradation of riparian and surrounding habitats. Woody IAPs, and transformer invaders especially, tend to transform riparian zones into woody monocultures, depleting habitat diversity and resilience, resulting in the degradation of riparian health. This degradation of riparian health is due to the loss of the roles that the indigenous riparian vegetation structure plays in the riparian system, such as resilience to, and attenuation of floods, bank soil binding and protection, provision of habitat niches and being an integral component of the local ecosystem. The invasion of riparian systems does not only produce detrimental impacts at the site and within the local habitat, but results in the degradation of surrounding ecological communities and downstream habitats through numerous hydrological, geomorphic and ecological processes.

Through review of literature and observations during field visits the following flowchart has been compiled to illustrate the authors' understanding of the processes and impacts of the dense invasion of riparian zones by alien invasive wattle. The flowchart integrates findings discussed in Chapters 2 to 4, and field observations made during the fieldwork component of this study. The following paragraph links the diagram to the literary and field evidence presented earlier in the document.

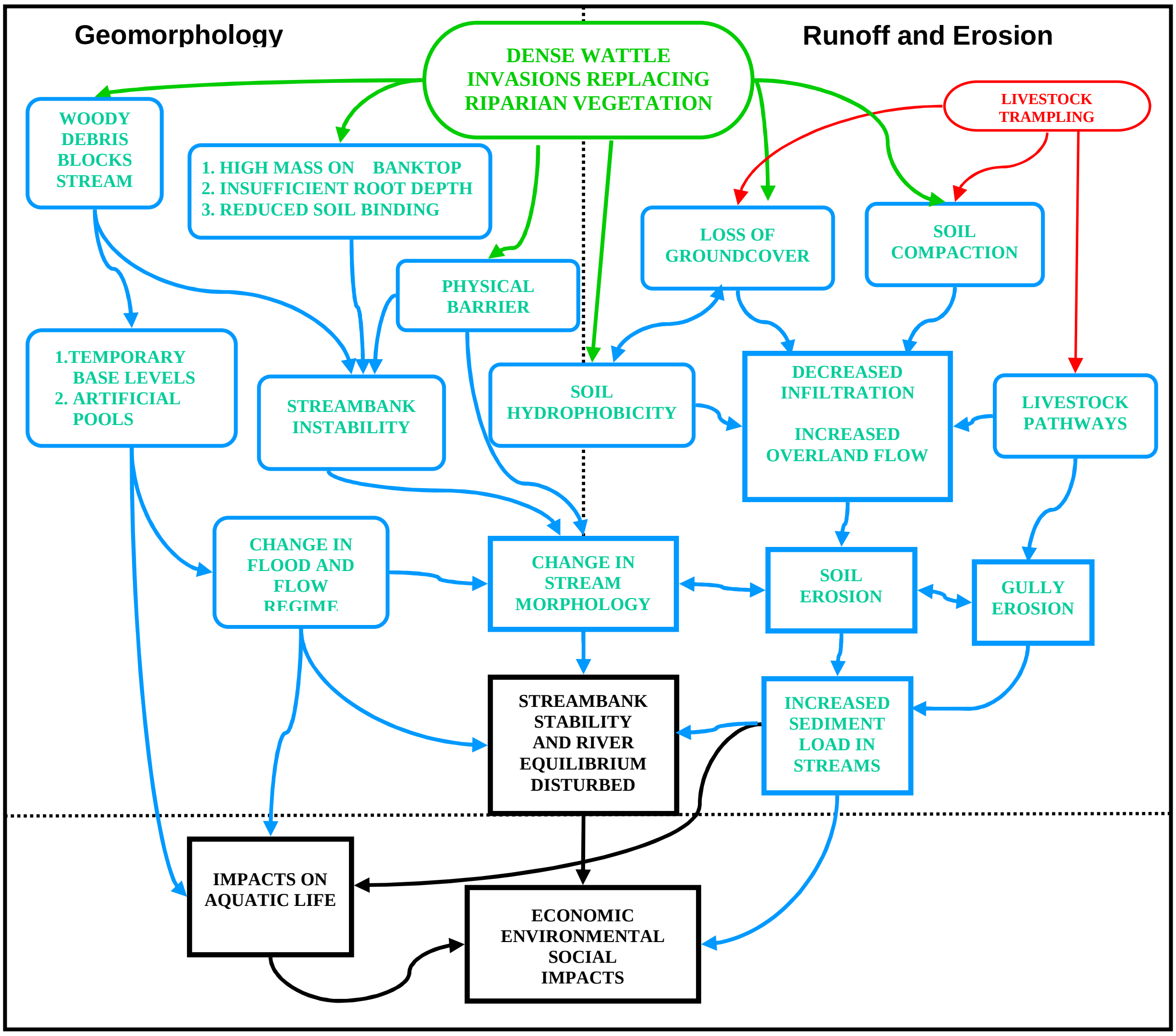

Figure 8.1 Potential impacts of invasive alien wattle on stream hydrogeomorphology and erosion within the riparian zone

In terms of the impacts of IAP invasions on geomorphology (Figure 8.1) the formation of woody debris dams and related impacts were noted by numerous researchers (Section 4.3). Observations during the fieldwork component of this study, utilising the MRHS method, found woody debris dams at all of the IAP infested Sites U1, C1 and C3, while none were present at the IAP cleared or natural sites (Section 7.1.6). A rise in stream bed base levels, and the formation of pools (Figure 8.1) upstream of the woody debris dams, was strongly noted at IAP infested Site C1, but also present at infested Sites U1 and C3 (Section 7.1.6). In terms of changes in flood and flow regime (Figure 8.1), the debris dams slowed flows, modified the patterns and sequences of flow biotopes and resulted in high flows flooding out of the channels more frequently, as noted by the presence of flood debris within vegetation of the riparian zone.

Rowntree (1991) in particular noted the impacts of woody IAPs on reducing bank stability particularly if rooting depth did not exceed bank height, but also through increased banktop mass and decreased soil binding (Figure 8.1). MRHS analysis of IAP infested Site C1 in particular showed numerous sections where woody IAPs growing on banktops had caused bank instability and collapse into the channel (Figure 7.18). Woody IAPs as a physical barrier were noted in the form of roots extending into the flow of the channel, and trunks and stems within the riparian zone trapping flood debris at all three of the IAP infested sites.

Loss of groundcover, soil compaction and soil hydrophobicity beneath dense stands of *A. mearnsii* was a well noted phenomenon within the literature (Section 4.1), and was most apparent at IAP infested Site C1 where the ground beneath the wattle stands was devoid of vegetative cover and the soil surface formed a sealed crust limiting infiltration (Figures 7.19 and 7.22). Lack of groundcover, livestock pathways, soil erosion and gulley erosion, most prevalent at IAP infested Site C1, was also linked to an increase in sediment loads within the IAP infested channels shown by an increased presence of sediment accumulations upstream of woody debris dams (Figure 7.20), and the higher prevalence of unvegetated bars within the IAP infested channels than within the natural sites (Section 7.2).

The findings from each of the field research components of this study are discussed in more detail within the following sections.

8.1 Modified River Habitat Survey

Selected data collected at each site through the MRHS forms were used to assess the streambank material, stream margin and bank features, banktop vegetation structure and the landuse or vegetation within 5m of the banktop. At the Umvoti sites, banks comprised predominantly of earth dominated the majority of transects, however some banks contained boulders and cobble. At the Cedarville sites, transects at natural Site C2 and lightly IAP infested Site C3 showed that banks were comprised exclusively of sands and gravels, producing friable banks which were rendered vulnerable to erosion where bank vegetative cover was lacking. IAP infested Site C1 contained dolerite-derived soils classified to the 'Earth' class, with most banks comprised exclusively of soil, and only selected transects showing the presence of boulder and cobble within the bank material. The dolerite-derived soils at Site C1, which were finer grained than the sands and gravels at Sites C2 and C3, produced banks which were more consolidated and less friable (Sections 6.2, 7.1.1 and 7.1.7).

Analysis of marginal and bank features highlighted that Umvoti natural Site U2 had a lower prevalence of both eroding and stable cliff banks (near vertical banks)when compared to IAP cleared Site U3 and IAP infested Site U1. The same trend was apparent at the Cedarville sites, where eroding cliff banks were far more prevalent at the infested Sites C1 and C3, than at the natural Site C2. This has particular relevance with Sites C2 and C3, located 1km apart on the same river, illustrating that the IAP infestation likely resulted in steeper banks that more regularly showed signs of being undercut (Section 7.1.2).

The banktop vegetation structure analysis (Section 7.1.3) highlighted that at IAP infested Sites U1 and C1 large woody IAPs were commonly present on the banktops, the point in the profile where woody IAPs have the potential to play the strongest role in increasing streambank instability. The woody IAPs increase the weight upon the bank, increasing the chance of bank failure, particularly if the rooting depth of the tree does not exceed the bank height, and the bank is undercut from scour around woody IAP roots within the flow channel. Also illustrated at Sites U1 and C1, was that the high density of IAP infestation generally precluded protective vegetative groundcover from growing on the banktops beneath the woody IAPs. At IAP infested site C3, which had a lighter density of woody IAP infestation, the MRHS data reflected that grass grew beneath the woody IAPs on the banktops at selected transects. This shows that at lighter woody IAP densities groundcover is more likely to survive, but once closed-canopy, dense infestation is reached, groundcover is commonly excluded.

Through capturing the vegetation and landuse within 5m of the banktop, the MRHS data reflected that at infested Site U1, wattle and a wattle/grass mix was the dominant vegetation cover within a 5m extent from the riparian banktops at the ten transects. This contrasted strongly with natural Site U2 and IAP cleared Site U3 where grassland was almost exclusively present. At lightly infested Site C3 the woody IAP wattle infestation was confined to the riparian macro channel, with grass being the dominant landcover beyond the banktops. At infested Site C1 it was shown that the high density of woody IAPs extended beyond the channel banks throughout all but one of the transects (Section 7.1.4). This supports the literature where it was noted that *A. mearnsii* tends to migrate along riparian zones, where after the infestation expands to the surrounding landscape (Section 3.3). Site C3 which was lightly infested most likely has a shorter infestation history than Site C1 which has become densely infested within the riparian zone, and which is expanding into the surrounding terrestrial landscape. This is confirmed further by the size of the larger invasive trees, which was observed to be older at Site C1 than C3 (Section 7.1.7.2).

Analysis of the channel heights and widths captured at each transect by the MRHS, in the form of a height-width ratio analysis, appears to indicate a stronger relationship between the height-width and the local hydrogeomorphological drivers of channel form at the sites, rather than the degree of infestation. This finding points to local hydrogeomorphological controls, such as valley form, bed gradient and flow volumes, being the dominant determinant of channel dimensions, as opposed to the influence of IAP invasion. The graph of the average height-width ratios indicates that all of the IAP infested and IAP cleared sites have channels that are narrower in relation to their depth than the natural sites, barring IAP infested Site C1. This finding suggests that IAP infestation of riparian zones results in channel incision, but that the template determined by hydrogeomorphological controls dominates channel dimensions more strongly (Section 7.1.5)

Site C1, being on average wider in relation to depth than the other incised IAP infested sites and natural Site C2, forms an outlier which could be explained by a number of factors. Bank face erosion caused through a severe reduction in vegetative groundcover and soil binding may have resulted in accelerated bank erosion, scour and collapse resulting in widening of the channel. Scouring and erosion of the streambank toe, facilitated by a lack of marginal zone vegetation, would result in undercutting of the steepening banks, and bank collapse, further widening the channel. A second possible explanation for the lack of incision when compared to the other IAP infested sites is that Site C1 flowed over bedrock in many sections, as indicated by the MRHS results, limiting channel downward incision. Debris damming was more severe at IAP infested Site C1 than at any of the other infested sites of the study.

Literature reflected that debris dams can result in channel widening in smaller headwater streams (Section 4.3), such as Site C1 which is located only 4km from its mountain top source.

The scatter plot graphs exploring height-width relationships with IAP invasion status (Figures 7.11 and 7.12) showed that transects at a site generally have a stronger relationship to each other, than to other sites of the same invasion status, which often fell clustered at a different section of the graph. This suggests there is a stronger relationship between height-width and the local hydrogeomorphological controls of a site, than the IAP invasion status of the site. The influence of IAP invasion on channel incision appeared to not have a severe enough impact to override the influence of the local hydrogeomorphic controls on the local channel dimensions. This finding is further reinforced by the scatter plot when comparing natural Site C2 and IAP infested Site C3, on the same river. These two sites clustered relatively close together considering their different IAP invasion status, also pointing to local hydrogeomorphic controls being the overriding determinant on channel dimensions.

Both alluvial and bedrock river bed types plot in a spread across the graph, indicating no trend between similar river bed types. This again points to local hydrogeomorphological controls, such as valley form, bed gradient (site variables – Figure 3.3) and flow volumes (catchment variables – Figure 3.3), being the dominant determinant of channel dimensions. Tight clustering of the transects of natural Site U2 shows that the channel dimensions at all ten transects of the site were uniform, possibly explained by good bank stability. This was in contrast to the two most densely IAP infested sites U1 and C1, which show the weakest clustering between the transects at each of these sites, possibly explained by bank instability and collapse, as well as debris dams, creating non-uniformity in channel dimensions at the site.

Through analysis of other sections of the MRHS collected through site observations (Section 7.1.6), channel form was reflected as a ‘deep incision’ at two of the three IAP infested sites and both of the IAP cleared sites. The height-width ratio analysis confirms this for all but Site C1, which was classed as ‘deep incision’ by observation but proved to not be so, based upon the averages of actual channel measurements. This highlights the danger of survey questions which are based upon qualitative observation, and which can be skewed by bias, prejudice or personal opinion.

In terms of the stream bed material captured, it can be seen that as with the height-width ratio analysis, there was a stronger relationship between channel incision and the degree of infestation than incision and the alluvial or bedrock dominated nature of the river reach (Table 7.2). Through observations, the presence of vertical banks that are both undercut and greater in height than 2m, was shown at all of the IAP infested sites. Undercut banks greater than 2m in height were however also present at the natural Site C2 (Table 7.2). This could be explained by either the presence of invasive *Salix* species or trampling of the riparian banks by livestock, or both, resulting in disturbance of bank groundcover and integrity, allowing erosion and scouring by the stream flow. The presence of eroding cliff banks was recorded as highest at one of the two IAP cleared sites and two of the three IAP infested sites (Table 7.2). This shows correlation with the findings of the Morphological Maps (Section 7.2), which showed that at the IAP infested Site U1, cliff banks dominated two of the three mapped sections. In terms of observations with regards to the percentage of the study reach choked by vegetation all of the IAP infested sites and one of the IAP cleared sites fell within the 33-67% choked class. The natural sites and one of the IAP cleared sites reflected less than 33%, showing a strong relationship between the extent of the reach choked and the degree of IAP infestation.

The photograph recording and analysis which forms a component of the MRHS (Section 7.1.7) showed that the following features were common, to varying degree, at all of the IAP infested sites;

- banks bare of groundcover vegetation, showing accelerated soil erosion at some sites,
- steep, undercut banks,
- unstable banks with woody IAPs growing on the banktops,
- collapsed banks, likely as a result of the banktop woody IAPs collapsing into the channels,
- woody IAPs both shading and falling into the channels,
- woody debris accumulating within the channels,
- debris dams present within the channels,
- stream bed level rise as a result of debris dams accumulating sediments,
- woody debris accumulated against woody vegetation within the floodplain,

- woody IAP roots extending into the flow of the channels, at some sites creating local scour and undercutting,
- the effects of soil hydrophobicity and loss of groundcover beneath *A. mearnsii*, and
- the advance of *A. mearnsii* out of riparian zones and into terrestrial habitats, such as indigenous grassland and forest.

(Note: photographs covering all features observed could not be included in the dissertation document)

In contrast the natural sites showed predominantly healthy channels which included;

- banks with good vegetative groundcover,
- banks which appeared stable and less vertical,
- significantly less undercut banks,
- absence of collapsed banks, and
- lack of woody debris.

8.2 Morphological Mapping

The IAP infested Morphological Maps highlight the following features;

- banks devoid of vegetation cover beneath woody IAPs,
- cliff banks,
- large amounts of woody debris
- a debris block which may develop into a debris dam
- a higher prevalence of channel bars, predominantly unvegetated, than at the IAP cleared or natural site Morphological Maps.

The Morphological Maps (Section 7.2) confirmed the features photographed within the IAP infested sites, that woody debris was present in large amounts, banks were predominantly devoid of groundcover and cliff banks dominated large sections of the channel length. The increased prevalence of unvegetated mid channel and side bars at the IAP infested sites may be an indication of the increased sediment loads associated with the erosion of channel banks devoid of vegetation, as well as undercut or collapsed banks upstream.

8.3 Channel Cross Profiles

From a visual assessment of the Cedarville site cross profiles (Figures 7.45 to 7.50), natural Site C2 appears to have a narrower channel width in relation to channel depth than IAP infested Site C3. This contrasts with the findings of the channel dimension data gathered by the MRHS, where the average height-width ratio reflects natural Site C2 to be wider in relation to channel height, than IAP infested Site C3. This inconsistency could be explained by GPS errors while plotting the cross profiles in the field (discussed in Sections 6.4.3 and 7.3). Greater faith is placed in the MRHS channel dimension measurements, and therefore the average height-width ratio analysis, as the physical measurements using measuring tapes proved more reliable.

The cross profiles of IAP infested Site C1 show no trend in being consistently wider or narrower than the other Cedarville sites, with C1 having high variation in channel dimensions. This is confirmed by the scatter plot relating channel height to width across all transects of the site, which shows a wide spread over the graph for the individual transects of Site C1. This lack of relationship could be due to non-uniformity in channel dimensions within the 500m study reach (as discussed in Section 8.1), or could be due to GPS errors under the dense canopy at Site C1. A second limitation of the method which could introduce errors was that at some transects an obvious banktop was present, while at others the bank merged seamlessly with the valley side. Where no obvious physical banktop was present, the channel height which periodically contains flow was estimated from a combination of features and characteristics. These included;

- flood lines estimated from visual site assessment,
- old flow debris accumulations within riparian zone vegetation,
- vegetation and topography indicators as per the DWAF (2005) guidelines "A practical field procedure for identification and delineation of wetland and riparian areas".

No strong relationships can be seen across the profiles at the Umvoti sites (Figures 7.51 to 7.54) and between the Umvoti sites and the Cedarville sites. Part of the reason for this could be that the channels were not as incised and sharply defined within the valley form as was the case at the Cedarville sites. The overall valley form of the Umvoti sites dominates the cross profile, with the channel form lost in the scale. However, focusing on just the flow channel portions of the Umvoti cross profiles it appears that the channel form at the U1 IAP infested sites (Figures 7.51 and 7.52) is wider and shallower when compared to the U2 natural sites (Figures 7.53 and 7.54). This contrasts with the findings of the channel dimension data gathered by the MRHS, where the average height-width ratio reflects IAP infested Site U1 to be narrower in relation to channel height, than natural Site U2 (Figure 7.24). The most likely explanation for this anomaly is the inaccuracy of the GPS cross profile data from Site U1. The physical measurements taken manually at all ten transects of Site U1 during the MRHS (averaged in Table 7.1) are a far more accurate representation of the channel dimensions at the site. As a result more emphasis is given to the results of the MRHS than the GPS cross profiles.

9. CONCLUSIONS AND RECOMMENDATIONS

This study has developed and tested a field methodology to investigate the potential impacts of woody IAPs on channel incision, bank steepening and streambank stability. In addition, the field methodology aimed to gather observations and data on various other impacts of woody IAPs on riparian zones, such as loss of vegetative groundcover, soil erosion within the riparian zone and woody debris accumulation within the channel. Through the use of the Modified River Habitat Survey (MRHS), modified and developed for this study, a diverse selection of qualitative and quantitative data were gathered.

Analysis of the data gathered by the MRHS showed that across seven sites, ranging from natural to IAP infested to IAP cleared, two of the three IAP infested sites (Sites C3 and U1) and both of the IAP cleared sites (Sites U3 and U4) showed evidence of having channels which were on average deeper in relation to their width, than the paired natural sites. However, the site most heavily impacted by IAPs (Site C1) showed the converse of the other two IAP infested sites, having a wider, shallower channel in relation to the natural paired site. One possible explanation for this anomaly is that Site C1 had a channel which ran over bedrock for significant portions of the 500m study reach, limiting downward incision. Secondly the channel contained debris dams which through observations on site, and literature review, are seen to potentially cause channel widening in headwater streams. While containing woody debris, IAP infested sites C3 and U1 did not contain the same density of debris which resulted in the formation of debris dams and bed level rise at IAP infested Site C1. Thus, two of the three IAP infested sites support the first statement of the hypothesis outlined in Chapter 1, that invasion of riparian zones by woody IAPs results in increased channel incision and bank steepening at the sites.

Site observations noted in the MRHS, and the analysis of site photographs taken in accordance with the methodology of the MRHS observed that all of the IAP infested sites, to varying degree, displayed banks of increased potential instability due to;

- steepening and undercutting,
- the presence of large woody IAPs growing on the banktops increasing banktop mass,
- evidence of collapsed banks and woody IAPs collapsing into the channels,

- woody IAP roots extending into the flow of the channels, creating local scour and undercutting at some sites,
- the accumulation of woody debris within the channel, and
- a lack of bank vegetative groundcover beneath the woody IAPs resulting in increased bank erosion.

Morphological Maps which contrasted biophysical features between the natural, IAP cleared and IAP infested sites confirmed aspects reflected by the MRHS, such as large amounts of woody debris causing channel blockages, banks devoid of vegetation cover beneath woody IAPs, and the presence of cliff banks. These and other findings discussed in Chapter 7, support the second and final statement of the hypothesis posed in Chapter 1, that invasion of riparian zones by woody IAPs results in an increase in streambank instability.

The overriding picture which can be interpreted from the results showing the relationships between the catchment and site variables controlling channel form (Figure 3.3) and invasion by woody IAPs, is that the catchment and site variables dominate the channel form template, but that this template is modified by woody IAP invasion. The extent of modification is difficult to quantify, with the number of site repetitions and level of data collected within the scope of this study, proving too limiting to establish modification extent.

The first objective for the study, outlined in Chapter 1, was to investigate the current body of knowledge covering the impact of woody IAP invasions on streambank stability and channel form. The review and exploration of literature within this dissertation provided valuable background knowledge and a base upon which to build and implement the field survey methodology, the second objective of the study. The data collected by the developed field methodology and survey tools proved useful for the analysis and investigation of the relationships between woody IAP infestation and channel form, barring the limitations discussed below.

The final objective of the study was to analyse shortfalls of the developed tools and methods, and suggest future research needs. An area of data collection that was found to be lacking at the conclusion of the study was an index of woody IAP invasion density, which could have been determined for each riparian bank at all transects to link the prevalence and location of the streambank and channel degradational features to the density of invasion. In this way invasion density could also be linked to impacts on the immediate stream section, and impacts which tend to accumulate and impact more heavily downstream, such as woody debris accumulation or sedimentation from upstream bank erosion. A soils analysis for each site would have enhanced understanding of the role of each soil in determining the stability and erodibility of the streambanks.

In the case of the UK RHS, the collected data is fed into a national database for storage and analysis. Manual methods of analysing the MRHS data showed some of the data to be of use in this study, while other data was not. The quantitative measurements of channel dimensions at each transect proved far more valuable in the analysis of woody IAP impact on channel form than the GPS cross profiles, particularly given the GPS errors at the sites with a closed canopy of woody IAPs.

For the results of the field case study to have been more conclusive a larger range of sites paired across rivers with more similar site and catchment variables is necessary. A longer term study would be ideal for this purpose, where catchment variables could be gauged utilising instruments such as recording rain gauges, runoff plots and streamflow meters. Erosion pins placed within riparian banks would be useful to record bank erosion and channel form change in a longer term study. Such instrumentation could measure channel form change after extreme events, when channels commonly undergo the most change. Such instrumentation and length of research was beyond the scope of this study.

The two key aims of the research study which were to;

- refine an international river habitat survey method for application within South Africa, and
- develop a test case to implement the developed method in analysing the impacts of IAPs on stream hydrogeomorphology in small headwater streams of KwaZulu-Natal, South Africa.

Discussion above illustrates that the MRHS developed for South Africa from the international river habitat survey method (UK RHS) was effectively modified for application within headwater streams of KwaZulu-Natal, but that methods of analysing all of the collected qualitative and quantitative data require further investigation. Secondly, the test case field application of the method to investigate the impacts of IAPs on streambank stability would have produced stronger findings had a larger sample of paired sites with similar geomorphological controls been found.

Considerable effort has been put into the research of IAPs in South Africa. Much of this effort has been fuelled by the governments' Working for Water programme. An important branch of this research has been the identification of methods, mechanical, chemical or biological, to eradicate and control invasive species. Although this branch of research is extremely important for the long-term management and ultimate conquest of the problem, the idea of total invasive alien eradication is still decades away, despite the vast progress, effort and money spent through the Working for Water programme. As a result researchers need to gain a thorough understanding of the processes of invasions across the full range of detrimental effects produced, to help managers, planners and policy makers address the existing problems caused by already infested and degraded systems, and to make more educated decisions in future environmental and resource management initiatives.

Additional insight is required into the processes of invasions and the impacts on the hydrogeomorphology of riparian zones and catchments. More research must be directed into understanding the impacts IAP invasions have on the physical habitat of riparian areas, which provide the framework for the biological and hydrological processes operating within South Africa's' riparian areas. The degradation of riparian zones is an issue that affects the entire country through the deterioration of water quality and quantity supply, and the potential loss or deterioration of valuable ecosystem goods and services.

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APPENDIX 1

Modified River Habitat Survey Form

2009

(after Environment Agency, 2003)

MODIFIED RIVER HABITAT SURVEY
TRANSECT KEY

F. PHYSICAL ATTRIBUTES

BANKS

BANK MATERIAL		BANK MODIFICATIONS		MARGINAL & BANK FEATURES	
NV	Not visible	**NK**	Not known	**NV**	Not visible
BE	Bedrock	**NO**	None	**NO**	None
BO	Boulder	**RS**	Resectioned	**EC**	Eroding cliff (earthy)
CO	Cobble	**RI**	Reinforced	**SC**	Stable cliff (earthy)
GS	Gravel/sand	**PC**	Poached	**PB**	Unvegetated point bar
EA	Earth (crumbly)	**BM**	Artificial berm	**VP**	Vegetated point bar
PE	Peat	**EM**	Embanked	**SB**	Unvegetated side bar
CL	Sticky clay			**VS**	Vegetated side bar
				NB	Natural berm

CHANNEL

CHANNEL SUBSTRATE		CHANNEL MODIFICATIONS		CHANNEL FEATURES	
NV	Not visible	**NK**	Not known	**NK**	Not known
BE	Bedrock	**NO**	None	**NO**	None
BO	Boulder	**CV**	Culverted	**EB**	Exposed bedrock
CO	Cobble	**RS**	Resectioned	**RO**	Exposed boulders
GP	Gravel / Pebble	**RI**	Reinforced	**VR**	Vegetated rock
SA	Sand	**DA**	Dam / Weir	**MB**	unvegetated mid-channel bar
SI	Silt	**FO**	Ford (man-made)	**VB**	vegetated mid-channel bar
CL	Clay			**WD**	Woody debris
EA	Earth			**DW**	Damming of channel by woody debris
PE	Peat				

FLOW TYPE / HYDRAULIC BIOTOPE

PO	Pool	**GL**	Glide	**CA**	Cascades
RI	Riffle	**CH**	Chute	**WF**	Waterfall
RU	Run	**RA**	Rapid	**BA**	Backwater

G. BANKTOP LAND USE AND VEGETATION STRUCTURE

WL	Wetland	**BR**	Invasive Bramble	**FB**	Fire break (bare earth)
GR	Grassland	**BW**	Invasive Bugweed	**RD**	Rock/scree
NO	Thicket	**WA**	Invasive Wattle	**IL**	Irrigated land
NK	Shrubland	**EG**	Exotic grasses	**PT**	Pasture
IF	Indigenous forest	**PP**	Plantation Pine	**TL**	Tilled land
		PW	Plantation Wattle	**DR**	Dirt road
		PE	Plantation Eucalypt		

HYDRAULIC BIOTOPE	DEFINITION
POOL	This feature has through flow at a very slow velocity. The combination of velocity and depth allows depositions of fine particulate matter over substrate of all sizes
RIFFLES	Flow over cobbles, gravel and boulders and have a shallow depth relative to bed material size. Consist of rapid, super-critical flow and indicate a distinct gradient change of the water surface. At increased discharge becomes a run.
RUN	Represented by tranquil flow, no broken water on the surface, with any substrate. No obvious stream bed gradient change. Runs have a higher depth to substrate size ratio than for riffles.
BACKWATER	A hydraulically detached feature where there is no through flow of water. Movement occurs through a single entrance/exit with low or no velocity. Are of variable depth, all substrate types, generaly covered in fine silt and sand.
CASCADES	Cascades consist of free falling water in step like fashion over bedrock.
WATERFALLS	Waterfalls are similar to cascades but higher. There is more free fall of water relative to horizontal movement. Height is the most important defining variable
GLIDE	This is a shallow, unconstricted, smooth flow over bedrock. Bed roughness is relatively low. It becomes a run over bedrock at higher flows.
CHUTE	This consists of a narrow constricted flow over bedrock Depth produces smooth flow at the surface. If flow becomes super-critical, the feature becomes a rapid.
RAPID	This feature is similar to a glide but has broken water. It occurs over bedrock or boulders. The critical feature is velocity, which must be high, together with the form ratios of width to depth, which must be low.

MODIFIED RIVER HABITAT SURVEY

A. FIELD SURVEY DETAILS

Page 1

Site no.____________________ River____________________

Belt transect no.____________

Date ____________ Time__________ GPS____________________

No of Photos taken____________________

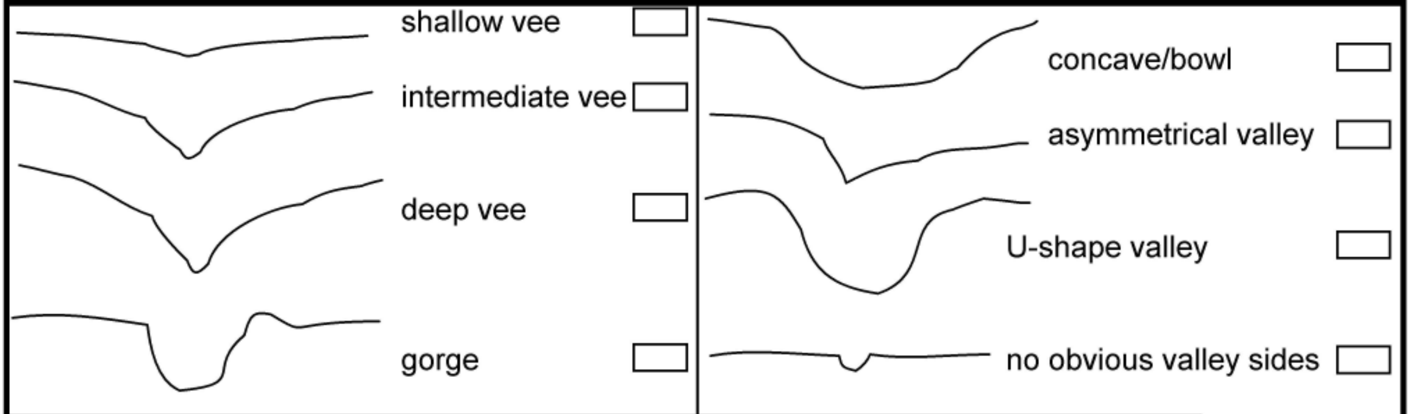
Adverse conditions affecting survey? Yes ☐ No ☐ Explain____________________

____

Site surveyed from: left bank ☐ right bank ☐ channel ☐

Is bed of river visible? Barely or not ☐ partially ☐ almost entirely ☐

B. PREDOMINANT VALLEY FORM



Distinct flat valley bottom? Yes ☐ No ☐ Natural terraces? Yes ☐ No ☐

C. PREDOMINANT CHANNEL FORM

Flat ☐
Slight incision ☐
Moderate incision ☐
Deep incision ☐
Over deepened ☐

D. NUMBER OF RIFFLES, POOLS AND POINT BARS

Riffle(s) ______ | Unvegetated point bar | Mid-channel bar(s) ______

Pool(s) ______ | Vegetated point bar(s) | Vegetated mid-channel bar(s) ______

Bedrock dominated channel? Yes ☐ No ☐

E. ARTIFICIAL FEATURES

	Major	Intermediate	Minor
Weirs / sluices	☐	☐	☐
Culverts	☐	☐	☐
Bridges	☐	☐	☐
Groynes	☐	☐	☐

Is channel obviously re-aligned?	No ☐	Yes < 33% ☐	Yes > 33% ☐
Is channel obviously overdeepened?	No ☐	Yes < 33% ☐	Yes > 33% ☐
Is water impounded by weir/dam?	No ☐	Yes < 33% ☐	Yes > 33% ☐

Notes ____________________

TEN BELT TRANSECTS ALONG STUDY REACH

F. PHYSICAL ATTRIBUTES (transect) Page 2

Belt transect number	1	2	3	4	5	6	7	8	9	10
Left Bank										
Material										
Bank modifications										
Marginal and bank features										
Right Bank										
Material										
Bank modifications										
Marginal and bank features										
Channel										
Channel substrate										
Flow type/Hydraulic biotope										
Channel modifications										
Channel features										

Braided channels? Yes ☐ No ☐ If yes then No. of sub-channels ______

G. BANKTOP LAND USE AND VEGETATION STRUCTURE (transect)

Belt transect number	1	2	3	4	5	6	7	8	9	10
Left Bank										
Landuse within 5m bank										
Left banktop										
Left bank face										
Right Bank										
Landuse within 5m bank										
Left banktop										
Left bank face										

H. CHANNEL VEGETATION TYPES (√) (transect)

Belt transect number	1	2	3	4	5	6	7	8	9	10
None(√)or not visible(NV)										
Mosses / lichens										
Broad leaved herbs										
Reeds/rushes/grasses										
Floating leaved (rooted)										
Free floating										
Amphibious										
Submerged broad leaved										
Submerged fine leaved										
Filamentous algae										
Bugweed										
Bramble										
Wattle										
Pine										
Eucalypt										

Other ☐ specify ______________________________

____

____

____

TEN BELT TRANSECTS ALONG STUDY REACH

I. CHANNEL DIMENSIONS (transect) Page 3

Belt transect number	1	2	3	4	5	6	7	8	9	10
Left Bank										
Bank top height										
Banktop height equal to bank full height? Yor **N**										
Right Bank										
Bank top height										
Banktop height equal to bank full height? Yor **N**										
Channel										
Bankfull width										
Water width										
Water depth										

Bed material: bedrock consolidated unconsolidated unknown

J. NOTES AND COMMENTS ON BELT TRANSECTS

Notes ____

K. VEGETATION COVER WITHIN RIPARIAN ZONE (√) (entire reach)

	Left	Right		Left	Right
Indigenous grass 1			Indigenous shrub 1		
Indigenous grass 2			Indigenous shrub 2		
Indigenous grass 3			Indigenous shrub 3		
Indigenous grass 4			Indigenous shrub 4		
Indigenous grass 5			Indigenous shrub 5		
Wetland vegetation			Rock / scree		
			Fire break		
Not visible			Commercial forestry		
Other ☐ specify_____			specify species_____		

L. BANK PROFILES (√) (entire reach)

	Left	Right		Left	Right
Gentle			Undercut < 0.5m		
Steep (>45°)			Undercut 0.5m - 1m		
Composite			Undercut 1m - 2m		
Vertical			Undercut > 2m		
Vertical with toe			modified - reprofiled		
Natural berm			modified - reinforced		
Other -specify_____			Other -specify_____		

M. EXTENT OF CHANNEL AND BANK FEATURES (√) (entire reach)

	None	Present	>33%		None	Present	>33%
No flow	☐	☐	☐	Eroding cliffs	☐	☐	☐
No perceptable flow	☐	☐	☐	Stable cliffs	☐	☐	☐
Smooth flow	☐	☐	☐	Vegetated mid-channel bars	☐	☐	☐
Rippled flow	☐	☐	☐	Unvegetated mid-channel bar	☐	☐	☐
Chute flow	☐	☐	☐	Vegetated side bars	☐	☐	☐
Standing waves	☐	☐	☐	Unvegetated side bars	☐	☐	☐
Exposed bedrock	☐	☐	☐				
Exposed boulders	☐	☐	☐				

N. CHOKED CHANNEL (√) (entire reach)

Channel choked with vegetation <33% ☐ | 33-67% ☐ >67% ☐

O. OVERALL CHARACTERISTICS (√) (entire reach)

Evidence of recent management

Mowing ☐ Burning ☐ IAP clearing ☐ Firebreak clearing ☐

Major impacts ____________________

Impacts by animals ____________________

Other ____________________

P. EXTENT OF INVASION (entire reach)

	Bramble		Bugweed		Wattle		Pine		Eucalyptus	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Isolated/scattered										
Regularly spaced, single										
Ocassional clumps										
Semi-continuous										
Continuous										
Shading of channel										
Overhanging boughs										
Exposed bankside roots										
Underwater roots										
Fallen into channel water										
Large woody debris										

Q. FEATURES OF SPECIAL INTEREST (✓) (entire reach)

Large woody debris	☐	Waterfall	☐
Debris dams	☐	Cascade	☐
Leafy debris in stream	☐	Braided channel	☐
Loss of groundcover	☐	Wetland	☐
Soil erosion	☐	Very large boulders	☐
Evidence of IAP clearing	☐	Other ☐ specify	______

R. INVASIVE ALIEN PLANTS (✓) (entire reach)

				Riparian zone		
	<33%	33-67%	>67%	<33%	33-67%	>67%
Bramble	☐	☐	☐	☐	☐	☐
Bugweed	☐	☐	☐	☐	☐	☐
Wattle	☐	☐	☐	☐	☐	☐
Pine	☐	☐	☐	☐	☐	☐
Eucalypt	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐

Notes ______

APPENDIX 2

River Habitat Survey 2003 Version

United Kingdom

(Environment Agency, 2003)

RIVER HABITAT SURVEY 2003 VERSION: SPOT-CHECK KEY Page 1 of 2

PHYSICAL ATTRIBUTES (SECTION E)

BANKS

Predominant bank material

NV = not visible

BE = bedrock
BO = *boulder*
CO = cobble
GS = *gravel/sand*
EA = earth (crumbly)
PE = peat
CL = sticky clay

CC = concrete
SP = sheet piling
WP = wood piling
GA = gabion
BR = brick/laid stone
RR = rip-rap
TD = tipped debris
FA = fabric
BI = bio-engineering materials

Bank modifications

NK = not known
NO = none

RS = resectioned (reprofiled)
RI = reinforced
PC = poached
PC(B) = poached (bare)
BM = artificial berm
EM = *embanked*

Marginal and bank features

NV = not visible (e.g. far bank)
NO = none

EC = eroding cliff (ⒺⒸ if sandy substrate)
SC = stable cliff (ⓈⒸ if sandy substrate)

PB = unvegetated point bar
VP = vegetated point bar

SB = unvegetated side bar
VS = vegetated side bar

NB = natural berm

CHANNEL

Predominant substrate

NV = not visible

BE = bedrock
BO = boulder
CO = cobble
GP = gravel/pebble (Ⓖ or Ⓟ if predominant)
SA = sand
SI = silt
CL = *clay*
PE = peat
EA = *earth*
AR = artificial

Predominant flow-type

NV = not visible
FF = free fall
CH = chute
UW = unbroken standing waves
CF = chaotic flow
RP = rippled
UP = upwelling
SM = *smooth*
NP = no perceptible flow
DR = *no flow (dry)*

Channel modifications

NK = not known
NO = none

CV = culverted
RS = resectioned
RI = reinforced
DA = dam/weir/sluice
FO = fôrd (man-made)

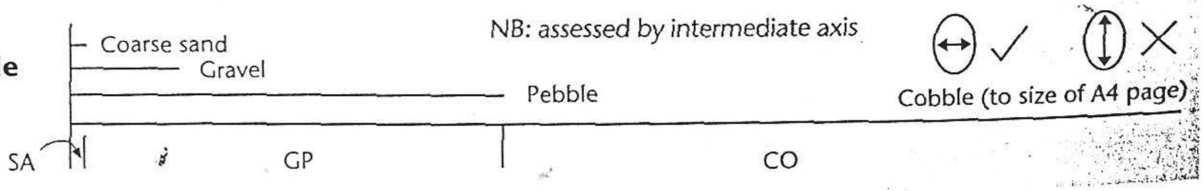
Channel features

NV = not visible
NO = *none*

EB = exposed bedrock
RO = exposed boulders
VR = vegetated rock
MB = unvegetated mid-channel bar
VB = vegetated mid-channel bar
MI = mature island
TR = Trash (urban debris)

FLOW-TYPES	DESCRIPTION
FF: Free fall	*clearly separates from back-wall of vertical feature ~ associated with waterfalls*
CH: Chute	low curving fall in contact with substrate ~ often associated with cascades
BW: Broken standing waves	white-water tumbling waves must be present ~ mostly associated with rapids
UW: Unbroken standing waves	upstream facing wavelets which are not broken ~ mostly associated with riffles
CF: Chaotic flow	a chaotic mixture of three or more of the four fast flow-types with no predominant one obvious
RP: Rippled	no waves, but general flow direction is downstream with disturbed rippled surface ~ mostly associated with runs
UP: Upwelling	heaving water as upwellings break the surface ~ associated with boils.
SM: Smooth	perceptible downstream movement is smooth (no eddies) ~ mostly associated with glides
NP: No perceptible flow	no net downstream flow ~ associated with pools, ponded reaches and marginal deadwater
DR: No flow (dry)	dry river bed

Scale



LEFT — **Banks are determined by looking downstream** — **RIGHT**

CHANNEL MODIFICATION INDICATORS

One or more of the following may be indicative of resectioning:

1. Uniform bank profile
2. Straightened planform
3. Bankfull width/bankfull height ratio <4:1
4. Uniform/low energy flow-types
5. No trees/uniformly-aged trees along bank
6. Intensive/urban land-use

LAND-USE WITHIN 5m OF BANKTOP (SECTION F) & 50m (SECTION H)

BL = Broadleaf/mixed woodland (semi-natural)
BP = Broadleaf/mixed plantation
CW = Coniferous woodland (semi-natural)
CP = Coniferous plantation
SH = Scrub & shrubs
OR = Orchard
WL = Wetland (e.g. bog, marsh, fen)
MH = Moorland/heath
AW = Artificial open water
OW = Natural open water
RP = Rough unimproved grassland/pasture
IG = Improved/semi-improved grassland
TH = Tall herb/rank vegetation
RD = Rock, scree or sand dunes
SU = Suburban/urban development
TL = Tilled land
IL = Irrigated land
PG = Parkland or gardens
NV = Not visible

BANKTOP AND BANKFACE VEGETATION STRUCTURE to be assessed within a 10m wide transect (SECTION F)

bare	B	bare earth/rock etc.
uniform	U	predominantly one type (no scrub or trees)
simple	S	two or three vegetation types
complex	C	four or more types

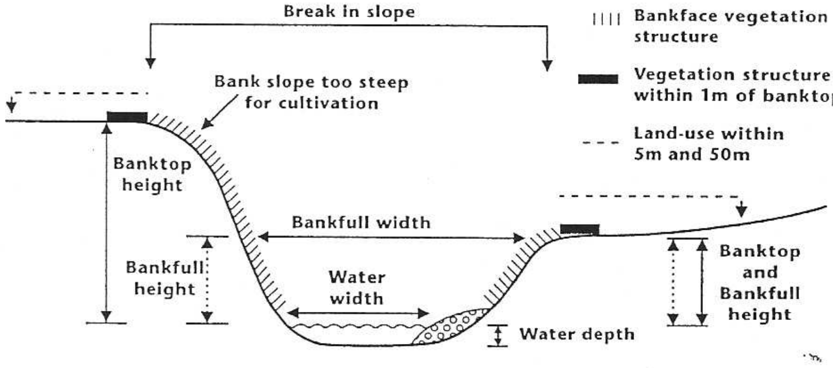
vegetation types

- bryophytes
- short/creeping herbs or grasses
- tall herbs/ grasses
- scrub or shrubs
- saplings and trees

Channel dimensions guidance (Section L)

- Select location on uniform section.
- If riffle is present, measure there. If not, measure at straightest and shallowest point.
- **Banktop** = first major break in slope above which cultivation or development is possible.
- **Bankfull** = point where river first spills on to floodplain.

Cross-section of channel showing definitions used to define where spot-check recording and channel dimensions measured



ENVIRONMENT AGENCY

EMERGENCY HOTLINE 0800 80 70 60

24 hour free emergency telephone line for reporting all environmental incidents relating to air, land and water.

A FIELD SURVEY DETAILS

Site Number: (leave blank if new site)

Site Reference:

Spot-check 1 Grid Ref:

Spot-check 6 Grid Ref:

End of site Grid Ref:

Reach Reference:

River name:

Date / /20   Time:

Surveyor name:

Accredited Surveyor code:

Is the site part of a river or an artificial channel? River ☐ Artificial ☐

Are adverse conditions affecting survey? No ☐ Yes ☐

If yes, state ....

Is bed of river visible? barely or not ☐ partially ☐ ±entirely ☐

Is health and safety assessment form attached? Yes ☐ No ☐

Number of photographs taken: ☐

Photo references:

Site surveyed from: left bank ☐ right bank ☐ channel ☐

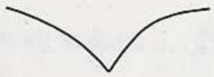
☐ **When options shown with 'shadow boxes', tick one box only**

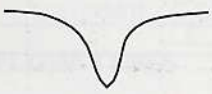
LEFT   banks determined by facing downstream   RIGHT

B PREDOMINANT VALLEY FORM (within the horizon limit) (tick one box only)

(tick one box only)


☐ shallow vee


☐ deep vee


☐ gorge


☐ concave/bowl


☐ asymmetrical valley


☐ U-shape valley


☐ no obvious valley sides

Distinct flat valley bottom? No ☐ Yes ☐   Natural terraces? No ☐ Yes ☐

C NUMBER OF RIFFLES, POOLS AND POINT BARS (enter total number in boxes)

Riffle(s) ☐   Unvegetated point bar(s) ☐

Pool(s) ☐   Vegetated point bar(s) ☐

D ARTIFICIAL FEATURES (indicate total number of occurrences of each category within the 500m site)

If none, tick box ☐

	Major	Intermediate	Minor		Major	Intermediate	Minor
Weirs/sluices				Outfalls/ intakes			
Culverts				Fords			
Bridges				Deflectors/ groynes/croys			
Other - state							

Is channel obviously realigned? **No** ☐ **Yes, <33% of site** ☐ **≥33% of site** ☐

Is channel obviously over-deepened? **No** ☐ **Yes, <33% of site** ☐ **≥33% of site** ☐

Is water impounded by weir/dam? **No** ☐ **Yes, <33% of site** ☐ **≥33% of site** ☐

SITE REF.	RIVER HABITAT SURVEY: TEN SPOT-CHECKS	Page 2 of 4

Spot-check 1 is at: upstream end ☐ downstream end ☐ of site (tick one box)

E PHYSICAL ATTRIBUTES (to be assessed across channel within 1m wide transect)

When boxes 'bordered', only one entry allowed	1 GPS	2	3	4	5	6 GPS	7	8	9	10	GPS
LEFT BANK	Ring EC or SC if composed of sandy substrate										
Material NV, BE, BO, CO, GS, EA, PE, CL, CC, SP, WP, GA, BR, RR, TD, FA, BI											
Bank modification(s) NK, NO, RS, RI, PC(B), BM, EM											
Marginal & bank feature(s) NV, NO, EC, SC, PB, VP, SB, VS, NB											
CHANNEL	GP- ring either G or P if predominant										
Channel substrate NV, BE, BO, CO, GP, SA, SI, CL, PE, EA, AR											
Flow-type NV, FF, CH, BW, UW, CF, RP, UP, SM, NP, DR											
Channel modification(s) NK, NO, CV, RS, RI, DA, FO											
Channel feature(s) NV, NO, EB, RO, VR, MB, VB, MI, TR											
For braided rivers only: number of sub-channels											
RIGHT BANK	Ring EC or SC if composed of sandy substrate										
Material NV, BE, BO, CO, GS, EA, PE, CL, CC, SP, WP, GA, BR, RR, TD, FA, BI											
Bank modification(s) NK, NO, RS, RI, PC(B), BM, EM											
Marginal & bank feature(s) NV, NO, EC, SC, PB, VP, SB, VS, NB											

← Enter channel substrate(s) not occurring as predominant in spot-checks but present in >1% of whole site.

F BANKTOP LAND-USE AND VEGETATION STRUCTURE (to be assessed over a 10m wide transect)

Land-use: choose one from BL, BP, CW, CP, SH, OR, WL, MH, AW, OW, RP, IG, TH, RD, SU, TL, IL, PG, NV

		1	2	3	4	5	6	7	8	9	10
LAND-USE WITHIN 5m OF LEFT BANKTOP											
LEFT BANKTOP (structure within 1m)	B/U/S/C/NV										
LEFT BANK-FACE (structure)	B/U/S/C/NV										
RIGHT BANK-FACE (structure)	B/U/S/C/NV										
RIGHT BANKTOP (structure within 1m)	B/U/S/C/NV										
LAND-USE WITHIN 5m OF RIGHT BANKTOP											

G CHANNEL VEGETATION TYPES (to be assessed over a 10m wide transect: use E (≥ 33% area), ✓(present) or NV (not visible)

	1	2	3	4	5	6	7	8	9	10	End
None (✓) or Not Visible (NV)											
Liverworts/mosses/lichens											
Emergent broad-leaved herbs											
Emergent reeds/sedges/rushes/grasses/horsetails											
Floating-leaved (rooted)											
Free-floating											
Amphibious											
Submerged broad-leaved											
Submerged linear-leaved											
Submerged fine-leaved											
Filamentous algae											

Use end column for overall assessment over 500m, including types not occurring in spot-checks (use ✓, E or NV) →

H LAND-USE WITHIN 50m OF BANKTOP Use ✓ (present) or E (≥ 33% banklength)

	L	R		L	R
Broadleaf/mixed woodland (semi-natural) (BL)			Natural open water (OW)		
Broadleaf/mixed plantation (BP)			Rough/unimproved grassland/pasture (RP)		
Coniferous woodland (semi-natural) (CW)			Improved/semi-improved grassland (IG)		
Coniferous plantation (CP)			Tall herb/rank vegetation (TH)		
Scrub & shrubs (SH)			Rock, scree or sand dunes (RD)		
Orchard (OR)			Suburban/urban development (SU)		
Wetland (e.g. bog, marsh, fen) (WL)			Tilled land (TL)		
Moorland/heath (MH)			Irrigated land (IL)		
Artificial open water (AW)			Parkland or gardens (PG)		
			Not visible (NV)		

I BANK PROFILES Use ✓ (present) or E (≥ 33% banklength)

Natural/unmodified	L	R	**Artificial/modified**	L	R
Vertical/undercut			Resectioned (reprofiled)		
Vertical with toe			Reinforced - whole		
Steep (>45°)			Reinforced - top only		
Gentle			Reinforced - toe only		
Composite			Artificial two-stage		
Natural berm			Poached bank		
			Embanked		
			Set-back embankment		

J EXTENT OF TREES AND ASSOCIATED FEATURES *record even if <1%

TREES (tick one box per bank)

	Left	Right
None	☐	☐
Isolated/scattered	☐	☐
Regularly spaced, single	☐	☐
Occasional clumps	☐	☐
Semi-continuous	☐	☐
Continuous	☐	☐

ASSOCIATED FEATURES (tick one box per feature)

	None	Present	E (≥33%)
Shading of channel	☐	☐	☐
*Overhanging boughs	☐	☐	☐
*Exposed bankside roots	☐	☐	☐
*Underwater tree roots	☐	☐	☐
Fallen trees	☐	☐	☐
Large woody debris	☐	☐	☐

K EXTENT OF CHANNEL AND BANK FEATURES (tick one box for each feature) *record even if <1%

	None	Present	E(≥33%)
*Free fall flow	☐	☐	☐
Chute flow	☐	☐	☐
Broken standing waves	☐	☐	☐
Unbroken standing waves	☐	☐	☐
Rippled flow	☐	☐	☐
*Upwelling	☐	☐	☐
Smooth flow	☐	☐	☐
No perceptible flow	☐	☐	☐
No flow (dry)	☐	☐	☐
Marginal deadwater	☐	☐	☐
Eroding cliff(s)	☐	☐	☐
Stable cliff(s)	☐	☐	☐

	None	Present	E (≥33%)
Exposed bedrock	☐	☐	☐
Exposed boulders	☐	☐	☐
Vegetated bedrock/boulders	☐	☐	☐
Unvegetated mid-channel bar(s)	☐	☐	☐
Vegetated mid-channel bar(s)	☐	☐	☐
Mature island(s)	☐	☐	☐
Unvegetated side bar(s)	☐	☐	☐
Vegetated side bar(s)	☐	☐	☐
Unvegetated point bar(s)	☐	☐	☐
Vegetated point bar(s)	☐	☐	☐
*Unvegetated silt deposit(s)	☐	☐	☐
*Discrete unvegetated sand deposit(s)	☐	☐	
*Discrete unvegetated gravel deposit(s)	☐	☐	

L CHANNEL DIMENSIONS (to be measured at one location on a straight uniform section, preferably across a riffle)

LEFT BANK		CHANNEL		RIGHT BANK	
Banktop height (m)		Bankfull width (m)		Banktop height (m)	
Is banktop height also bankfull height? (Y or N)		Water width (m)		Is banktop height also bankfull height? (Y or N)	
Embanked height (m)		Water depth (m)		Embanked height (m)	

If trashline lower than banktop, indicate: height above water (m) = width from bank to bank (m) =

Bed material at site is: consolidated ☐ unconsolidated (loose) ☐ unknown ☐

Location of measurements is: riffle ☐ other ☐ (state)

M FEATURES OF SPECIAL INTEREST Use ✓ or E (≥ 33% length) *record even if <1%

None	☐	Very large boulders (>1m)	☐	Backwater(s)	☐	Marsh(es)	☐
Braided channels	☐	*Debris dam(s)	☐	Floodplain boulder deposits	☐	Flush(es)	☐
Side channel(s)	☐	*Leafy debris	☐	Water meadow(s)	☐	Natural open water	☐
*Natural waterfall(s) > 5m high	☐	Fringing reed-bank(s)	☐	Fen(s)	☐	Others (state)	☐
*Natural waterfall(s) < 5m high	☐	Quaking bank(s)	☐	Bog(s)	☐		
Natural cascade(s)	☐	*Sink hole(s)	☐	Wet woodland(s)	☐		

N CHOKED CHANNEL (tick one box)

Is 33% or more of the channel choked with vegetation? No ☐ Yes ☐

O NOTABLE NUISANCE PLANT SPECIES Use ✓or E (≥ 33% length) *record even if <1%

			bankface	banktop to 50m		bankface	banktop to 50m
None	☐	*Giant hogweed	☐	☐	*Himalayan balsam	☐	☐
		*Japanese knotweed	☐	☐	*Other (state).........................	☐	☐

P OVERALL CHARACTERISTICS (Circle appropriate words, add others as necessary)

Major impacts: landfill - tipping - litter - sewage - pollution - drought - abstraction - mill - dam - road - rail - industry - housing mining - quarrying - overdeepening - afforestation - fisheries management - silting - waterlogging - hydroelectric power

Evidence of recent management: dredging - bank mowing - weed cutting - enhancement - river rehabilitation - gravel extraction - other (please specify)

Animals: otter - mink - water vole - kingfisher - dipper - grey wagtail - sand martin - heron - dragonflies/damselflies

Other significant observations: if necessary use separate sheet to describe overall characteristics and relevant observations

Q ALDERS (tick one box in each of the two categories) *record even if <1%

*Alders? None ☐ Present ☐ Extensive ☐ | *Diseased Alders? None ☐ Present ☐ Extensive ☐

R FIELD SURVEY QUALITY CONTROL (✓ boxes to confirm checks)

Have you taken at least two photos that illustrate the general character of the site and additional photos of any weirs/ sluices and major/intermediate structures across the channel?	☐
Have you completed all ten spot-checks and made entries in all boxes in E & F on page 2?	☐
Have you completed column 11 of section G (and E if appropriate) on page 2?	☐
Have you recorded in section C the number of riffles, pools and point bars (even if 0) on page 1?	☐
Have you given an accurate (alphanumeric) grid reference for spot-checks 1, 6 and end of site (page 1)?	☐
Have you stated whether spot-check 1 is at the upstream or downstream end of the site (top of page 2)?	☐
Have you cross-checked your spot-check and sweep-up responses with the channel modification indicators given on page 2 of the spot-check key?	☐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150 m
Image © 2009 DigitalGlobe
©2009 Google
lat -29.208930° lon 30.400422°
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© 2009 Cnes/Spot Image
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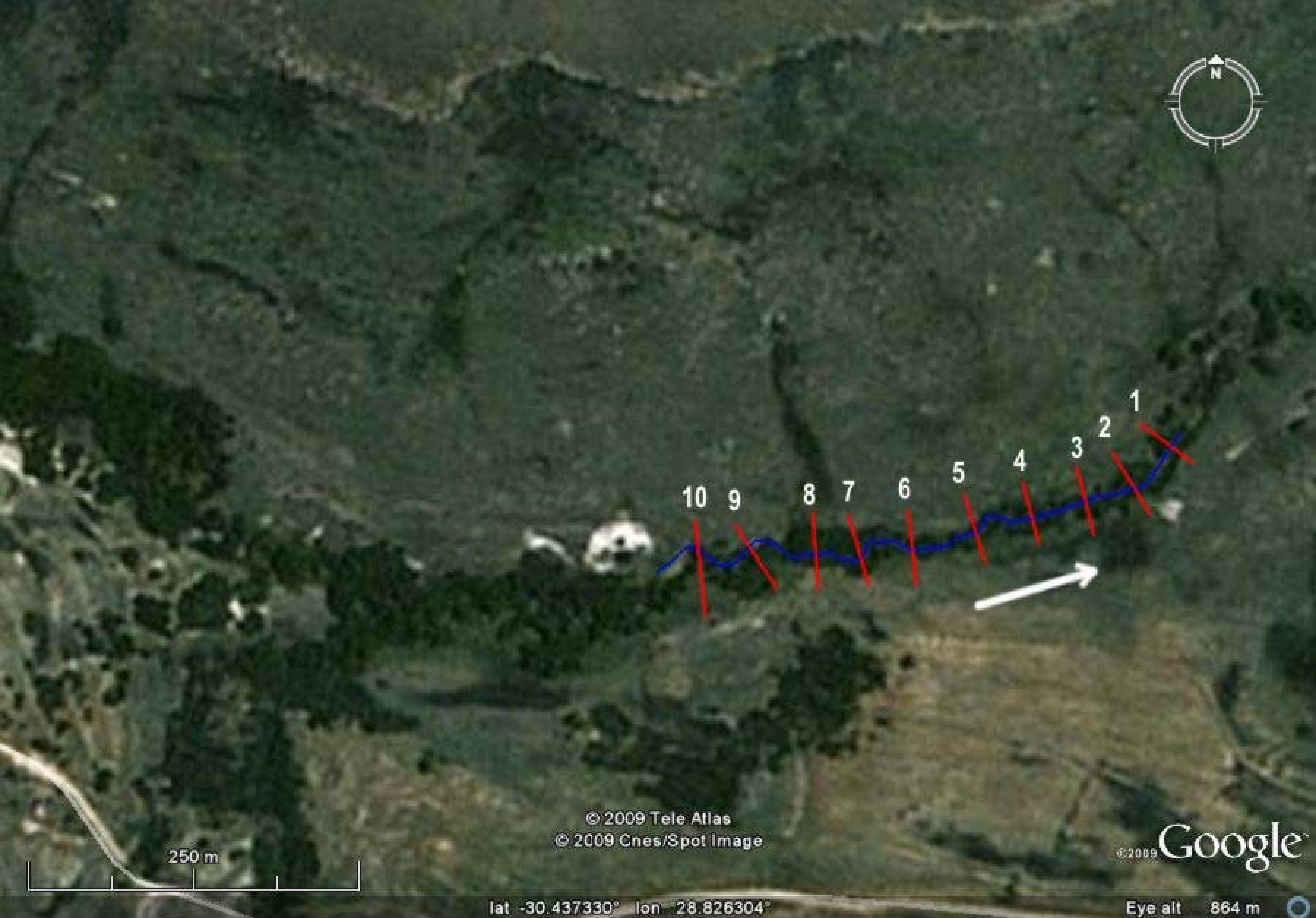

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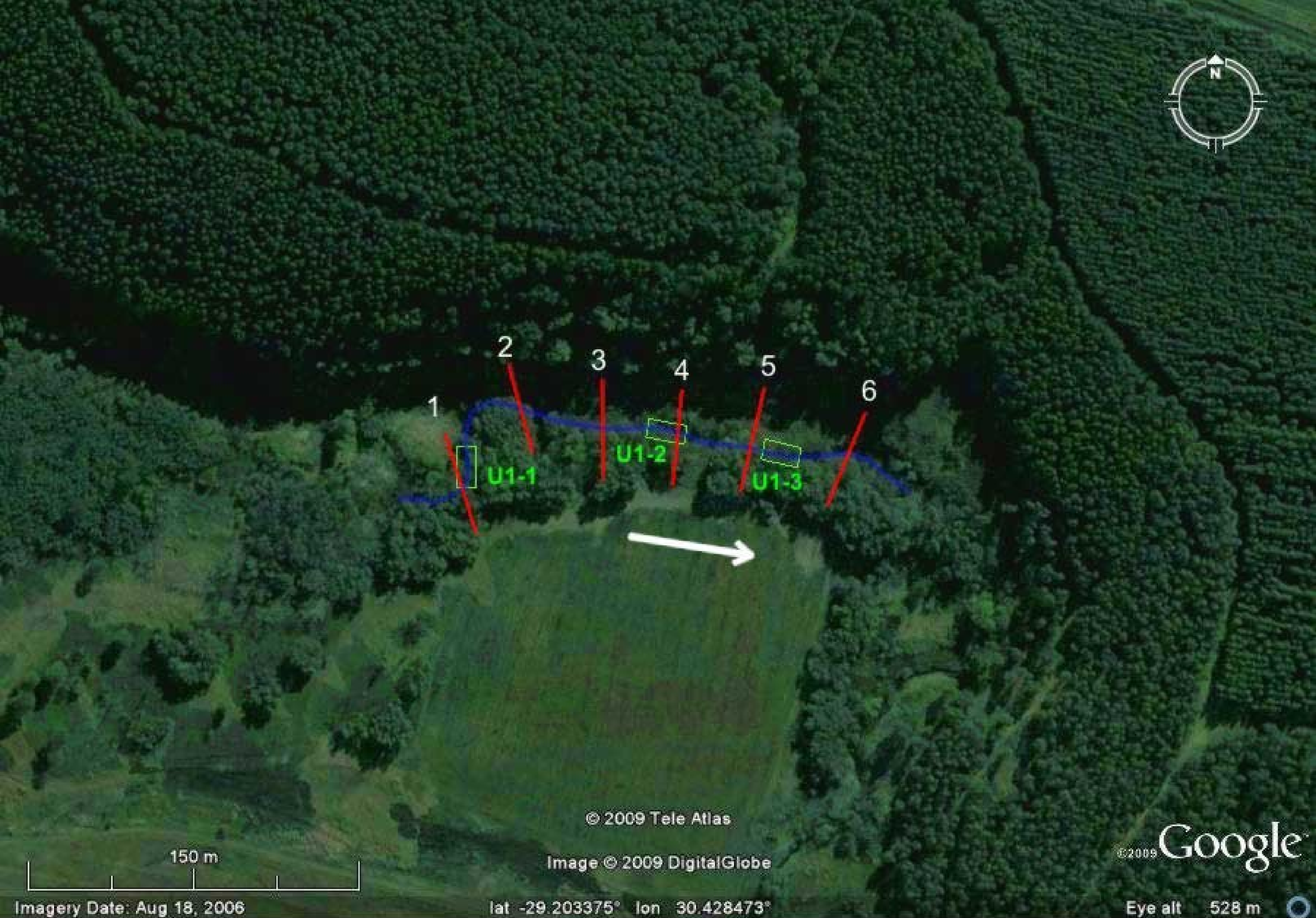

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Image © 2009 DigitalGlobe
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