OUR CHANGING RIVERS

An introduction to the science and practice of Fluvial Geomorphology

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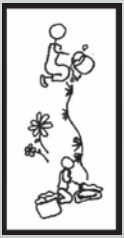

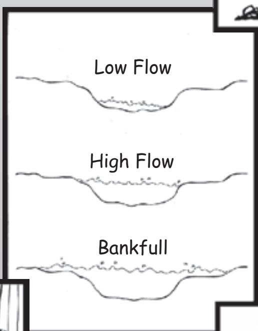





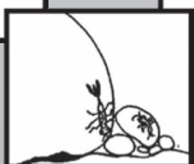



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Table of Contents

➢ headings within main sections ☞ text enhancing information boxes

Clarifying the Text

We have tried to write this book in a form that is easy to understand and interesting to read. But before you get started, we want to clarify a few terms. In this book:

- A "**river system**" is a general term meaning the *entire* river system (i.e. from beginning to end, from catchment to river mouth).

- The term "**river environment**" is an umbrella term. Associated with it are the individual components that make up a river system, i.e. the specifics at ground level. Things like: vegetation, areas where animals and insects live (e.g. river banks and river beds), the river water and all of the things that are in the water – rocks, sediment, sand, pebbles and more. All of these specifics are components that make up **a river environment** which **is part of a river system.**

- Finally, when we talk about geomorphologists, we are talking about *fluvial* geomorphologists.

This book will introduce you to the science and practice of fluvial geomorphology and explain what this science has to do with understanding rivers; in particular, how rivers respond to change – caused naturally and/or by human influences.

As you read, you will learn about rivers, the components that make up a river environment and how these components respond to change – in particular, change caused by water management schemes.

By the time you finish this book, you will know what hydraulic biotopes are and how they can influence cow populations. You will understand the difference between an impoundment and an IBT. You will understand the importance of "sustainable development", and you will be well versed on the tricks of the geomorphology trade (i.e. how rivers are assessed and classified). Not only that, but you will learn many interesting facts about water and see how river science relates *directly* to your life.

And that's just the beginning!

We hope you enjoy the watery adventure of Our Changing Rivers and have as much fun reading this book as we did writing it.

uMhlatuze River: downstream from Phobane Lake & Goedetrouw Dam
Nkwaleni Valley - Kwa-Zulu Natal

Sipho Mandla told us that he used to love riding his motorbike on his father's farm. He used to love taking off at full speed towards the river and plowing through the sandy beaches, kicking up sand as he rode with the wind stinging his eyes until tears streamed down his cheeks. For him, there was no better ride than along the banks of the uMhlatuze. But that was years ago. Now, he says the beaches are practically gone and the ride isn't nearly as good. "The uMhlatuze has changed," he told us forlornly. "I'm not sure why, but it has."

Percy Smith tells us that over the last several years, he too has noticed changes in the uMhlatuze. But the changes he has noticed do not leave him feeling forlorn like Sipho; in fact, he says he feels quite the opposite. Percy says he is happy with the "new" uMhlatuze because it provides him with a constant supply of water for his crops, pretty much all year round. Plus, his irrigation pumps hardly ever clog with silt anymore *and* he no longer has to dig trenches or canals to find, and then guide, elusive winter river water back to where he needs it most – in his fields and orchards. "All of these changes have been fine with me", he beamed, giving us a thumbs up.

And then there's Leroy du Preez. Leroy misses tubing down the river with his mates and beach parties on the weekends. Before the uMhlatuze changed, he used to partake in these activities on a regular basis. But now it has been years since he floated along with his drinks tied to his tube trailing behind him.

"Technically we could still tube down the river" he told us, shrugging his shoulders as he looked towards the "new" uMhlatuze with disdain (he was showing us around his favourite picnic spot). "But if you look over there," he pointed down stream, "you can see there are spots where the vegetation encroaches so thickly from the river banks that you battle to get by. So it's hardly worth it to bother now."

"Besides," he added in a nervous whisper, "the channel is much narrower than before and there are more crocs in the river than there used to be, so tubing might not be conducive to survival, if you know what I mean". He said this with a nod, a nudge of his elbow, and a very serious look in his eye. We knew exactly what he was getting at. Who would want to tube down a river if there were crocs in it?! We certainly wouldn't.

Obviously, over the last few years, something has happened to the uMhlatuze River that has changed the way it looks and how much water flows down it. What could it be? And what does a geomorphologist have to do with finding out?

What is fluvial geomorphology and what does a fluvial geomorphologist do?

Geomorphology is a science that studies the relief features (land shapes and forms) of the earth. Fluvial geomorphology is the study of relief features shaped by the action of running water. Mountains, valleys, flood plains, hills, cliffs and crevices are all examples of relief features that have been shaped in some way by water, and fluvial geomorphologists study *how* water has shaped them. Whether it's a glacier sculpting out a mountain valley, or a river carving a pathway to the sea, geomorphologists want to know about it.

Recently, fluvial geomorphologists have been asked to apply their science and their expertise to river management. This is because fluvial geomorphologists are, essentially, experts on river systems and how they work. Fluvial geomorphologists study everything that a river is made of – from pebbles in the water to how fast the water flows – in order to find out what condition a river is in. All of the information that they gather is then organized and put into charts. With this information, geomorphologists are able to give advice about how to protect rivers and manage their water supply as **an important resource**.

> **Did you know?**
>
> The modern science of geomorphology has been developing for over half a century.

There are a multititude of interconnected components that make up a river system, and geomorphologists study many of them. They look at how these interconnected parts influence each other and how they respond to

<u>Water: An Important Resource</u>

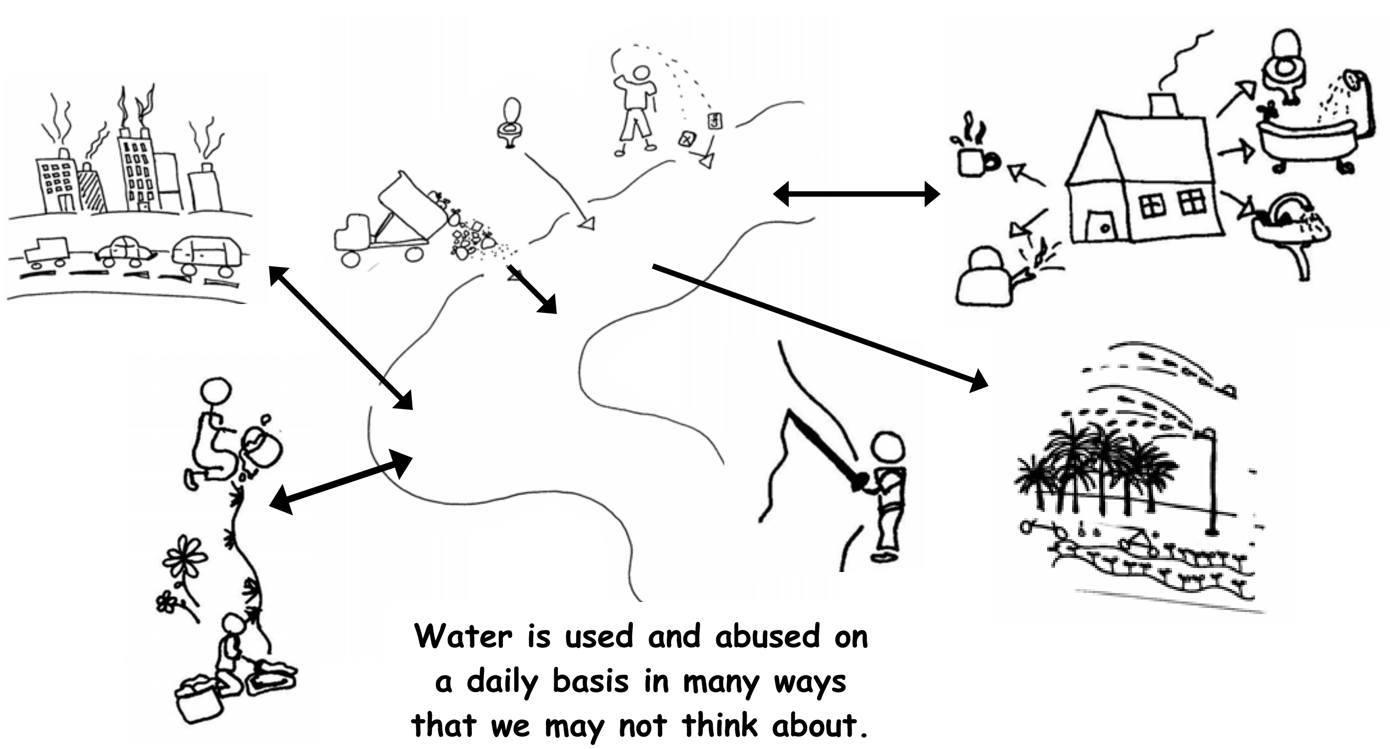
Conservation of a river channel is important because river channels carry fresh water, and without fresh water nothing can survive. Plants, animals, insects and humans would disappear completely. Water keeps us alive. The food that we eat needs it to grow – plants and animals. **Did you know that less than one percent of all the water on the planet is fresh?**

Everything that is alive on the planet needs water to live. Therefore, it becomes clear that conserving the quality of fresh water, and managing it as a valuable resource, is very important to the future of the planet and all that inhabit it. Which is why, more and more, geomorphologists are being called upon to give advice about how to manage and conserve fresh water as a precious resource.

change, in the short term and in the long term. Geomorphologists also look at the factors that *cause* change in a river system, whether they are natural or due to human influences. Most important to geomorphological studies, however, is understanding the impact that change to a river system causes in a river environment. Geomorphologists want to know, understand and where possible be able to predict **change and the effects of change** in a river system. In this way, the information that geomorphologists are able to provide to water management schemes can be invaluable.

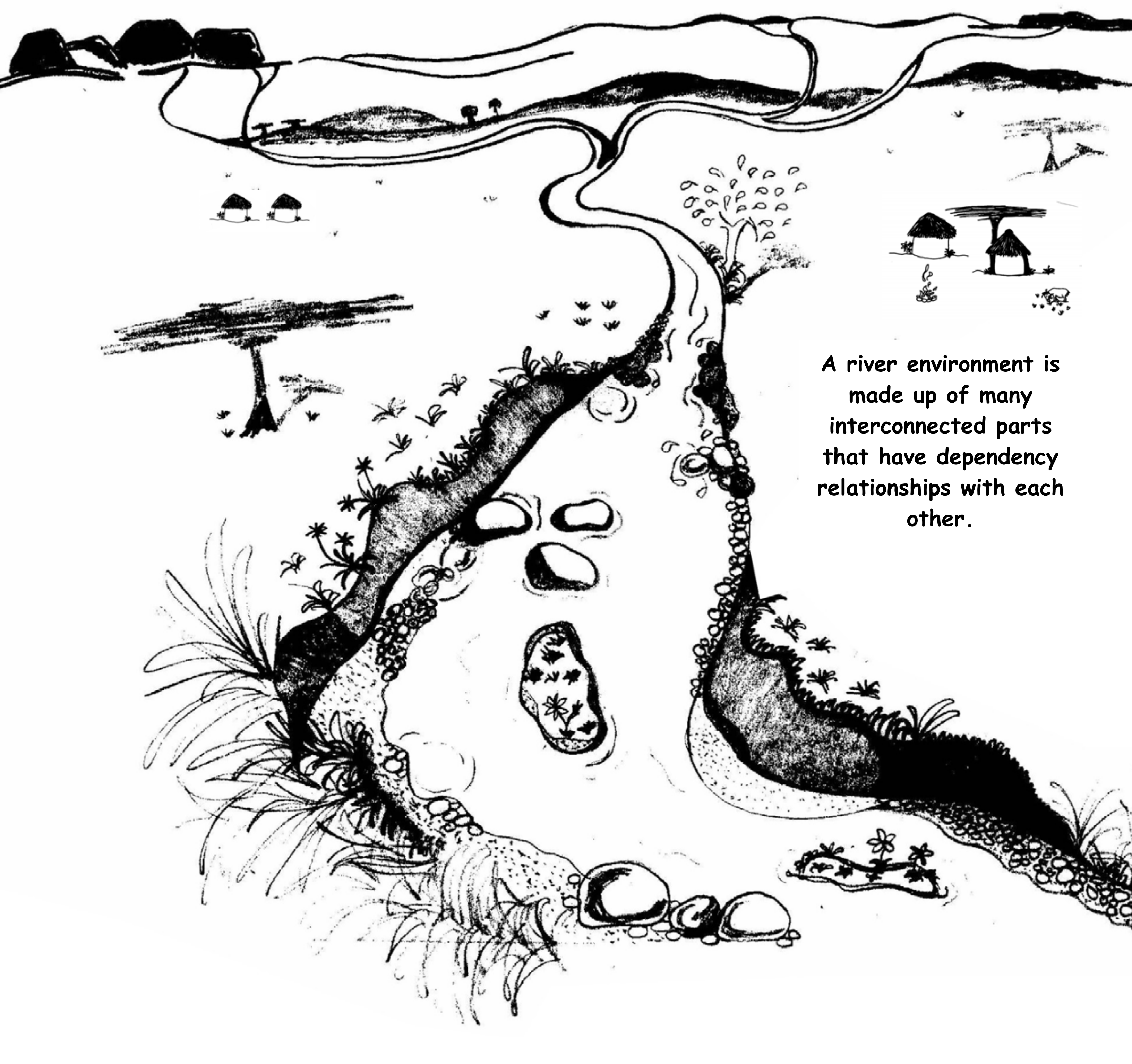
These days, as populations, towns, cities, agricultural communities and industries grow the natural environment is being placed under increasing strain. As a result, how we use our water resouces is becoming that much more important. In order to ensure that there is enough water for everyone, water supplies need to be managed. Managing water means organizing how water resources are used and seeing that they are used efficiently, effectively and sustainably so that people, towns, cities, agricultural communities *and* the environment can all benefit. The hope is to achieve water management schemes that will provide *water for all* without causing irreparable damage to a river system's natural environment.

South Africa gets a large portion of its water supply from its rivers, and the amount of water that is present in our rivers varies greatly from time to time, causing the supply to be unreliable. There are two main ways in which this variability of supply can be managed. One, is to store river water and control how and when it is released. The other, is to transfer river water from an area that has an abundant supply, to an area that has very little. River water is stored or "impounded" when a dam is built on a river; it is transferred in something called an "interbasin transfer scheme" (IBT). Both of these water management methods will be explained after we introduce you to the exciting world of a river environment.



Water is used and abused on a daily basis in many ways that we may not think about.

Discovering Rivers and the Components of a River Environment



A river environment is made up of many interconnected parts that have dependency relationships with each other.

Discovering Rivers and the Aspects of a River Environment

When geomorphologists study a river they look at the river system as a whole but they also study the components that make up the river environment. Components are identifiable features that characterize a river environment. Geomorphologists observe them because they vary from river to river, and because they are largely dependent upon the flow and sediment regime of the river. Components are also important because their condition or "health" is indicative of the general health/state of the river channel.

When rain falls in a rural village, water runs down the roads. As it does, it begins to form grooves, taking bits of sand, rock and soil with it. How deep the grooves become will depend on how much it rains and how fast the rainwater flows down the road. It will also depend on what kind of material the road is made of. If the road is made of hard rock, there is little chance that flowing water will be able to make a groove in it during one storm; however, if the road is made of clay, the chances are higher that the water will make a significant groove. This is because clay is softer than rock. The same is true if the road is made from sand, rocks and soil that have been pressed together from many years of people walking on them. If a large amount of rain water flowed down this kind of road, it would definitely cause grooves. In fact, chunks and pieces of this kind of road could wash away during a heavy storm as water disrupts the compacted sand particles and dislodges rocks that the sand held in place. This same action, of water carving through landscape, is true with a river but on a much grander scale.

Did you know?

The source of the river is where it begins. The mouth of the river is where it opens up into the sea, or where it ends.

The River Environment

A river system is fed by a drainage basin or catchment, and is made up of many eco-systems. A **catchment** is the land surface that contributes water and sediment materials to a river channel. **Ecosystems** are individual ecological units that consist of **biotic** and **abiotic** factors. Every ecosystem that exists within a river system consists of a combination of all the factors that make up the river environment; these include living organisms (e.g. insects, fish, birds, animals, vegetation), and environmental features such as temperature, flowing water, materials that make up the bottom of a river bed, and rainfall.

*Living organisms are called "**biotic**" factors and environmental features are called "**abiotic**" factors.*

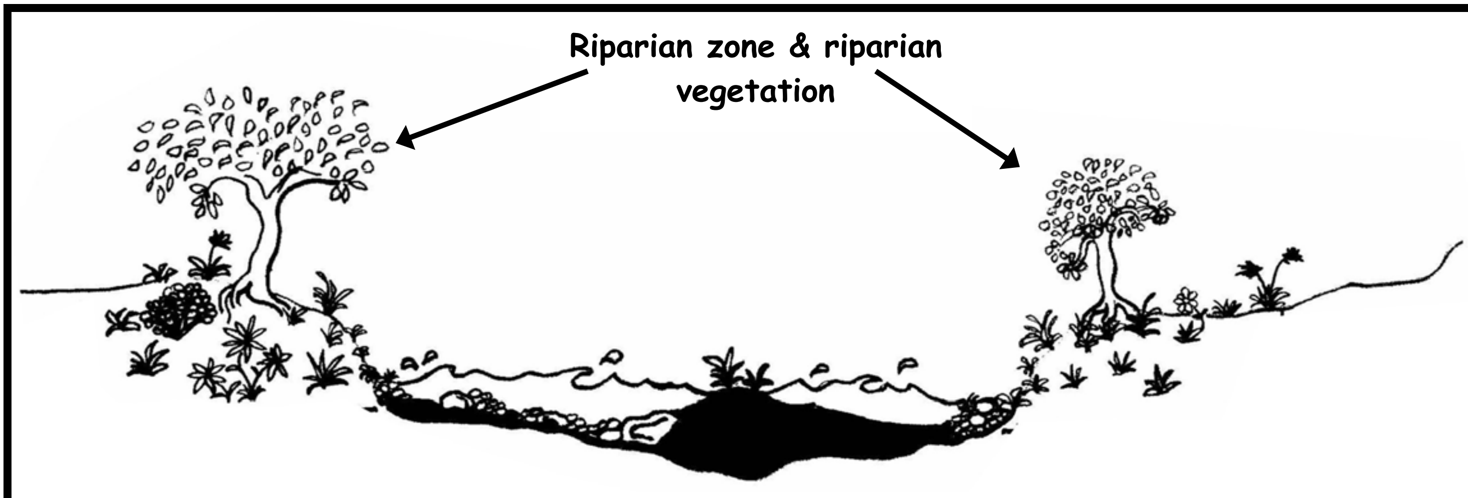
A river is often formed by rainwater falling onto a catchment area and then flowing down the hillsides where it meets at a common point. This common point forms the beginnings of a river channel. Just like water that flows down a road in a rural village when it rains, a river will carve a path through a landscape, dislodging cobbles and rocks along the way, and carrying sand and soils until it comes to an end; for example, by flowing into the sea, emptying into a lake, or spreading itself over wetland areas (like the Okavango Delta).

Fast Facts

A river that flows all year round is called a **perennial** river. A river that only flows for part of the year is called a **non-perennial** river. A non-perennial river is seasonal and may only flow during wet seasons, remaining dry for the rest of the year. A river that only flows when it storms is called an **ephemeral** river.

As a river flows, it becomes the source of water and life for many plant and animal species. A variety of tree and vegetation types will grow and proliferate along the banks of a river as they make use of the water supply for growth and reproduction. People also congregate around rivers and water sources for the same reasons: food, water and sustainability of life. For all the biotic components of a river environment, and for all of the people that depend upon it for survival, unpolluted river water is crucial to ensuring life over death. This is because unpolluted river water is a sustainer of life and the foundation for growth and propagation of species. This is always important to remember when considering development and the future of waterways in South Africa and around the world.

A very important part of a river environment is called the riparian zone. **The riparian zone** lies adjacent to the river channel and is closely linked to it. Ecosystems in the riparian zone depend on water, sediment, and nutrients carried by the river. The riparian zone can be found along the banks of a river and can include some form of flood plain.
A more detailed explanation of a flood plain is yet to come, but for now it is



When a river changes, so does its riparian zone.

important to know that a **flood plain** is a flat area of land that often gets covered with water during a flood. The characteristics that a flood plain exhibits depend upon how often it is flooded and what kind of sediment materials are left behind after the floodwaters subside. Flood plains are geomorphological features formed by a river during flooding events. They support an important group of ecosystems called the riparian ecosystems. These are ecosystems that are directly associated with the riparian zone – the health of the riparian zone will determine the health of these ecosystems. In turn, the health or state of the riparian zone depends upon the state or health of the river channel.

The riparian zone is an important area because it provides natural ***habitat*** for many different kinds of vegetation, plant communities, and certain kinds of aquatic species and wild life. Geomorphologists pay great attention to this area because whether or not it survives depends upon what is happening in the river channel. This dependency relationship is reliant upon the quantity of the water that flows down the channel (the link between river channel and riparian zone is the river's water supply). Water flow is one of many natural occurrences that take place in a river system. These occurrences are called "channel processes".

Crucial Goods and Services:
gifts from a freshwater river

→ The goods and services that a river provides are compromised when water quality and quantity is poor. Fresh, clean water in amounts that support sustainability makes all the difference to being able to harvest a river's goods and services - building materials, food, medicine and drinking water are but a few.

Channel Processes

Channel processes are events or actions that result in change or movement within a river system. Natural flood flows, differences in water levels according to weather changes, natural shifting of materials within the river channel (rocks and sand for example), and natural maintenance of habitat areas such as the riparian zone, are all events that can be classified as "channel processes". These processes work in a way that keeps a river system in a **dynamic state of equilibrium**.

When a river can maintain itself (its shape and form) and the life associated with its environment in a balanced way this is called a "natural state of **equilibrium**". This state of equilibrium is known as **dynamic** because it is not static – it encompasses change. The channel consistently undergoes natural change but, at the same time, responds to such change in a way that does not permanently compromise or damage the living systems that make up the river environment. An example of a channel process that maintains a dynamic state of equilibrium in a river system is a flood.

A large flood could cause a great amount of damage to a river channel and its riparian zone when it inundates the river channel with enormous amounts of fast flowing water. However, the system is able to recover over time as flood waters subside and re-establishment of species and their associated ecosystems takes place. This can happen because river banks are able to recover through a process of deposition that helps restabilize river banks that were eroded during the large flood event - we will learn more about the processes of erosion and deposition just now.

What is important about a *dynamic state of equilibrium* is that it *works in a way that maintains a sustainable river environment*. When something is "**sustainable"** it is able to carry on its natural processes without running out of resources. In the case of a river system, its main resource is water; a sustainable river system would have enough water to support the aspects and processes of its natural environment in a dynamic state of equilibrium.

> Habitat
> ► The place or environment where a plant or animal naturally lives and grows.
>
> Aquatic
> ► Growing or living in water

When events occur that alter natural channel processes, the state of equilibrium gets upset. This is called "**disequilibrium**". Even though a river environment will go through inevitable phases of natural disequilibrium – like during a flooding event or a drought – the river system has a natural recovery period because the events that cause the disequilibrium are not permanent. As mentioned, flood waters subside and rains eventually come to restore balance in a river system experiencing drought conditions. Conversely, when humans cause disequilibrium in a river environment, it is not always done in a balanced way. For example, when a river management scheme is put into place it causes *permanent* changes to how the water flows down the river channel – these are not changes that will go back to the way they were because the river management scheme will not "subside" like flood waters, or bring rains to remedy drought conditions. It is the state of disequilibrium caused by human interference, which is of most concern to geomorphologists when it comes to river management.

How a River Works: the basics

Although rivers come in many shapes and sizes, the basics of every river are the same. These basics include: a flow and sediment regime; a river channel that is active at some time during the year, if not all year round; and some form of aquatic species living or vegetation growing in the river environment.

Flow & Sediment Regimes

The velocity or speed at which water travels determines if it can move sediment and how much sediment it can move. This ability to move sediment is known as the "transport capacity" (TC). The transport capacity of a river depends on two things in particular: 1) How much water runs down the channel, and 2) How steep the channel is. It is important to note that there is a distinct relationship between flow and velocity. As flow increases so does velocity, but they are not the same and their relationship depends on river type. **Discharge is the volume of water, velocity is the speed of water, and a flow regime is the pattern of the volume of the flow, or the discharge.**

A "**regime"** is a term that refers to something that happens on a regular or consistent basis, and that displays a characteristic pattern over time. The term "**flow regime**" refers to the season by season and year by year pattern of the regular flow of water down a river channel, as well as all of the processes associated with that water flow. The same is meant for the term "**sediment regime**" only it refers to the processes associated with the movement of *sediment* down a river channel.

Every river has its own unique flow and sediment regimes. These work in tandem and are responsible for shaping a river's morphoplogy, as well as for providing the surroundings in which the components of the river environment are able to grow and function.

Geomorphologists want to understand the flow and sediment regime of a river in order to know how the regimes influence the river system as a whole. They also want to get a good grasp on the impact each river's flow and sediment regime has on its river environment. Although flow and sediment regimes work together, they can be defined as separate things.

Flow

The shape or morphology of a river channel is largely dictated by its flow regime. The term "**flow regime**" refers to the water that flows down the river channel - how much water, how deep or shallow, how often the river channel floods, how fast or slow, how strong the flow is - all of these water actions in a river channel make up its flow regime. The flow regime is

Substrate

► A general term that encompasses all of the materials on the bottom of a river bed: sediment and bedrock included.

Sediment

► Is the material that settles to the bottom of a river but that is also moved by the flow regime. Sediment can be sand, silt, pebbles, and rocks of increasing size.

Bedrock

► Mostly rock material, bedrock is not carried down the river channel by the flow regime. It is the permanent bottom of the river bed found below mobile sediment materials.

responsible for eroding, transporting and depositing channel sediments. The magnitude and frequency of a flow regime are directly related to the formation of river channels and the transport of sediment materials. **Magnitude** refers to *how much* water is flowing and **frequency** refers to *how often*. An understanding of magnitude and frequency is necessary for effective river management.

A good example of a river channel's relationship with magnitude and frequency of flow would be a flood. How often a river floods, coupled with how high and fast the flood waters flow, will cause inevitable changes to the shape of a river channel. As you have learned, when the morphology of a river channel is affected, so are the aspects of the river environment. By remembering these dependency relationships you are well on your way to thinking like a fluvial geomorphologist.

Physical Geography & Fluvial Geomorphology

To understand the physical geography (i.e. the physical characteristics) of a region means to know specifically what the hills, mountains, and fields are made of. It may seem obvious that they are all composed of soil and rocks, but all over the earth there are many different kinds of soil and rock and not all areas are made up of the same kind. Geomorphologists want to know the physical geography of a region so that they can best understand how it will respond to running water. Some kinds of soil and rock will wash away or erode quicker than other kinds. This will make a difference to the shape or morphology of a river channel.

The physical geography of a region also determines how steep a river channel is – the degree of steepness is known as the **gradient**. Gradient also plays a role in shaping a river channel's flow regime.

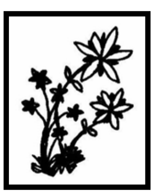
The physical geography of a region will also make a difference to the kinds of ecosystems that develop there, and to the types of vegetation that will take root throughout a river system.

The question for fluvial geomorphologists is, just how *much* of a *change* can magnitude and frequency undergo (i.e. via a water management scheme) before irreparable change is caused to the morphology of a river channel?

Sediment

Materials that make up **sediment** are anything from mud, made up of tiny grains of silt and sand, to pebbles and rocks, as well as pieces of dead vegetation. Any non-living material that enters a river channel from its catchment or from the banks of the river, and is moved by the flow of water at some point, is considered as sediment. The sum movement of sediment, how much and how fast, is called a **sediment regime**.

The river bed below mobile sediment materials is permanent because it is either too heavy or too solid to be moved by running water. This immobile bottom is called **bedrock**. Bedrock is, basically, the geology of a river channel and coupled with alluvium can influence the shape of a river channel.



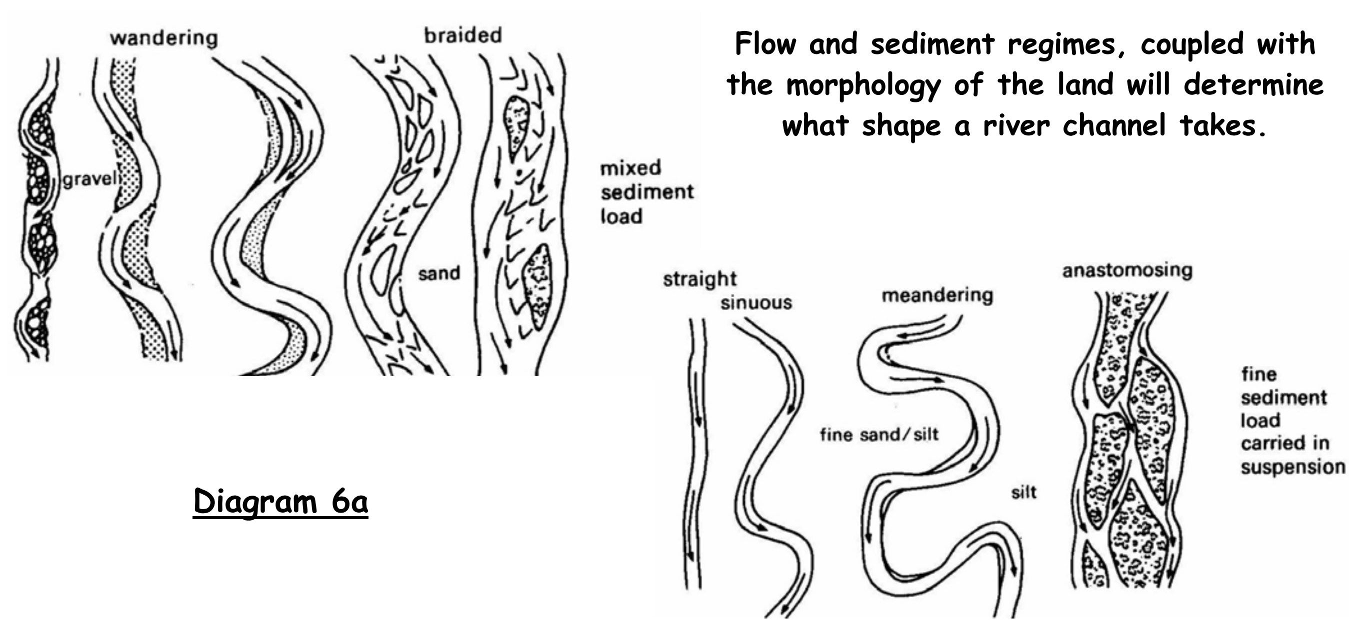
Bedrock and Alluvium

There are three kinds of river channel. The **two main types
are bedrock** and **alluvial**. The third type is called a **mixed channel**, which is made up of both bedrock and alluvial sections.

In **bedrock channels,** the geology of the river bed and its resistance to erosion are the main determinates of channel form. Such channels have been termed “controlled” channels as their form is determined by bedrock controls rather than by flow.

In contrast, **alluvial channels** form within alluvium/sediment that is moved by the flow regime. Cobbles, gravel, sand or silt, and even boulders are all forms of alluvium. The form or morphology of an alluvial channel is mostly controlled by three things: river flow, the rate at which sediment is supplied, and the size of sediment deposits. These three things constantly adjust when change is imposed upon a flow regime - they also have a great influence on the morphology of the river channel.

The morphology of alluvial channels adjusts due to the transportability of their main channel shapers (i.e. alluvium/sediment). Have a look at some of the different shapes that alluvial channels can take under influence of different flow and sediment regimes, and erosional and depositional forces (Diagram 6a).



Flow and sediment regimes, coupled with the morphology of the land will determine what shape a river channel takes.

<u>Diagram 6a</u>

Channel Forming Factors

It is important to keep in mind, when considering river systems, that a river channel is not formed by a single water flow event. There are different kinds of discharge (rates and quantities of flow) taking place over long periods of time that, coupled with climatic events and variable channel conditions, influence its formation and morphology.

Erosion, Deposition and the Macro-Channel

When water moves a large amount of sediment, more than can be replaced by natural catchment processes, the banks of a river can wear away and the channel can start to get deeper and wider – this is called **erosion**. In contrast, if there is a significant amount of transportable sediment in or entering a river channel and the flow regime is unable to carry it over different gradients or past obstructions, a *build up* of sediment materials can occur. This build up is called **deposition**. Deposition can take many forms and can occur in many places along the length of a river channel: along the banks, at tributary junctions, even against boulders or in the shallows of flowing rivers (thereby creating sandy islands). Deposition can also occur when sediment gets caught in vegetation.

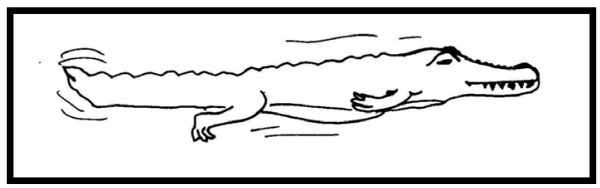
> **Erosion**
> ► The wearing away of rocks or soils by running water.
>
> ---
>
> **Incision**
> ► When a river channel gets deeper as a result of flow changes - as river channel cutting deeper into the land.

Erosion and deposition determine the immediate morphology of a river channel by making the banks wider and the channel deeper, or by constructing other morphological features such as benches, islands, and flood plains.

It is important to note that while erosion occurs in one part of a river channel, deposition takes part in another as the materials that were eroded are moved and recycled into different areas. As channel processes, erosion and deposition are important for rejuvenating flood plain ecosystems because they clear away old vegetation and create new spaces for re-growth.

Finding the macro-channel…

It is during flooding events that most of the geomorphological work that shapes a river takes place. Floods are short-lived events that occur for only a small percentage of time, maybe less than 5% of an entire year. Between floods are "low flows" or **normal flow**. This normal flow provides the main habitat for the species that live in the river. Normal flows (which themselves can be quite variable) are confined to what is known as the **active channel**.



The **active channel** is the part of a river channel that receives water flow most often. It is usually marked by noticeable banks on either side of the channel. When high flow causes water to reach the edges of these banks it is called "**bankfull**". Bankfull discharge is thought to control the form of alluvial channels and, because flow resistance reaches a minimum at bankfull stage due to the limited influence of river bed obstructions on flow velocity, it is during bankfull that the channel is thought to operate most efficiently for the transport of water and sediment.

The term "bankfull discharge" is sometimes used interchangeably with the term "**effective discharge**". This can tend to get confusing; luckily, one of South Africa's leading experts on fluvial geomorphology was able to help clarify exactly what the two terms mean in relation to river systems.

Bankfull Discharge vs. Effective Discharge

Q & A with Dr. Mud

Q: What does "bankfull" *mean*? What is bankfull discharge? How is it different from effective discharge or dominant discharge?

A: *Bankfull is the point at which the flow comes up to the top of the bank, just before it goes out onto the flood plain or equivalent. The effective discharge is the discharge that, in the long term, transports the bulk of the sediment load. This is on account of its magnitude and frequency – a sufficiently high magnitude to transport sediment at a sufficiently high frequency. Bigger floods do not happen often enough, smaller floods do not have sufficient energy to cause significant transport.*

Dominant discharge is a concept used to express the notion that there is one flood size that dominates the channel in terms of geomorphological work. It is often thought to be the bankfull discharge. Thus bankfull discharge, effective discharge and dominant discharge may all be the same, though in some systems bankfull and effective discharge may be different, in which case there may be two dominant discharges – the effective discharge controlling sediment transport and the bankfull discharge controlling channel form.

Q: How is bankfull discharge relevant to the river channel – i.e. why does it matter?

A: *Bankfull discharge is important because it is thought to be the discharge that controls the overall form of the channel – its width, depth, meander wave length, distance between riffles etc. Therefore, when trying to define an equilibrium condition it would be done in terms of bankfull discharge. Alternatively, the equilibrium may be better described in terms of effective discharge where this is different. Or there may not be a recognizable equilibrium.*

***Note that in a system that is in disequilibrium, incision of the channels will throw out the bankfull relationships because bankfull will only be achieved by much larger floods.*

…continuing on with channel form…

The **flood plain** is a more or less level area found above the bankfull mark. It is often covered with water dependent vegetation. A flood plain is formed when the bankfull discharge is exceeded and flood waters spread out onto the adjacent land, depositing sediment and providing soil for riparian vegetation. Sometimes these floods can be erosive and can wash away sediment, uproot trees, and carry away vegetation, thereby creating spaces for new individuals to become established.

There are different degrees and sizes of flood plain. Some might be large and support an extensive and varied riparian zone – these are known as "true" flood plains. But others, depending on the morphology of the channel, might only be small bench type features. In any case, a flood plain plays an important role whether it is extensive or not.

Armouring, Scouring and Erosion

Armouring is a condition of the river bed that results from the selective erosion of fine material. It occurs when flow velocities are high enough to remove fine sediment such as silts and sands or even fine gravels, but are not high enough to remove the larger gravels, cobbles and boulders. These form a protective layer over finer material beneath. Further erosion of this finer material can only occur when a big flood overturns the large surface material and exposes the finer materials beneath.

Scouring takes place during high flow events and is a process during which sediment materials of varying sizes and weights are moved downstream or shifted in position.

Interestingly, true flood plains are not a frequent feature of South Africa's rivers. This is because many of our rivers are incised into former flood plains (from times long ago) that now form terraces well above the normal level of flooding. These terraces are often utilized for agriculture because of their good soils and the elevated protection they offer from flooding events. Unfortunately, however, this protection is not always reliable, especially during extreme flooding events like those caused by cyclone Demoina in 1984 or cyclone Eline in 2000.

All of the aforementioned river channel action is often "enclosed" or bordered by another bank marker called the "**macro-channel"**. The macro-channel is **the most outer river bank marker that distinguishes the "borders" of a river channel, inside of which all channel processes occur**.

All of these channel and "bank" markers provide different types of information that help fluvial geomorphologists understand river systems and channel processes. For example, by identifying the active channel, bankfull, and macro channel marks, geomorphologists can speculate about the actions of a flow regime during any given season, as well as identify how dependent riparian vegetation is on varying water levels.

A quick review: bankfull, effective discharge & the macro-channel…

Some of the following information you might recognize from the Q & A with Dr. Mud – this is intentional as we want to be sure that the concepts of different kinds of discharge are clear, because they all mean something different to the sustainability of a managed river system.

Rivers are shaped by a variety of different flows that occur at differing frequencies. Bankfull discharge – the flow which comes just to the top of the active channel banks – occurs on average in most river systems once a year or once every two years. At this flow, the velocity is high enough to move materials on the river bed and to carry finer materials that are brought in by soil erosion in the catchment. This flow also occurs frequently enough to be effective (i.e. influence channel morphology) in the long term. For this reason it is often termed the **effective discharge**. **Bankfull discharge is**, therefore, **a flow that can perform much geomorphological "work", and is believed to be responsible for the bulk of the sediment transport and for shaping the channel**. The width and depth of the channel can be related to the bankfull discharge. So can the size of meanders or the distance between riffles. (Don't worry; you are very close to finding out exactly what a "riffle" is.)

Smaller floods that are contained within the channel occur more frequently but have lower depths and velocities. They also have a limited capacity to move sediment. These flows may be able to move sand or silt, but are unable to move the larger gravels or cobbles that make up the beds of many rivers. Thus, although they occur more frequently than the bankfull discharge, these lower flows are less effective in terms of the geomorphological work that they perform.

Floods that are larger than bankfull overtop the banks and spread out onto the flood plain where erosion and deposition may occur as described above. These larger floods also have greater energy for erosion and sediment transport within the channel itself, but because they occur less frequently than the bankfull discharge, their long-term effects are smaller.

Very large floods also cause considerable short term change to a river channel through both erosion and deposition. In 2000, very large floods transformed the Sabie, Olifants and Letaba rivers in the Kruger National Park, turning sand bed rivers to bedrock rivers in some areas, and depositing large banks of sediment in others. Trees on islands in the middle of these rivers were ripped out by the flood. Over time, these channels are likely to change back to something more like what they were before the floods, as the regular annual floods reshape the sediment and vegetation comes back to colonize sediment deposits.

Why does all of this matter?

Engineering activities (e.g. water management schemes) that regulate flow often change the magnitude and frequency of flows. Storing water behind a dam wall inevitably results in a reduction in the frequency of flows able to reach the top of the channel banks. This, in turn, results in a reduction in the effective discharge of the impounded river channel. As the long-term sediment transport capacity is reduced, sediments are deposited in the channel; as a result, the channel becomes smaller. Conversely, an interbasin transfer scheme may increase flows to such an extent that the erosive capacity of the flow is greatly increased, resulting in a significantly larger or deeper channel.

How much a river channel changes following a flooding event also depends on how quickly a river and its associated riparian zones recover from the flood. For example, if re-vegetation is rapid and an adequate amount of sediment has been deposited; reconstructive processes can happen quickly

Vegetation and the Morphology of a River Channel: not just a pretty face

It is important to know that the shape of a river channel does not solely rely upon flow and sediment regimes; vegetation also plays a very important role in maintaining channel morphology.

How quickly the banks of a river erode depends largely upon the types of vegetation that grow in a river's riparian zone. This is because certain types of vegetation contribute to river bank stability while others can cause instability by making the banks more susceptible to collapse. The stability or instability of vegetated river banks depends on the root system of the plants that are growing there.

Root systems that make a difference…

Vegetation influences the morphology of a river channel in many ways. For example, most vegetative root systems act to give cohesion to channel morphology by holding together the sediment materials that make up the river banks. In this way, some root systems can affect the stability of river banks by acting as a trap for sediment materials, and building up or maintaining the banks. As a result, river banks can become more resistant to the erosive forces of channel water flows. Not all vegetative root systems are cohesive, however, and some do contribute to bank instability. Often, this instability or stability depends upon the nature of the root system and on how deep or shallow the system grows.

Grass root systems are a good example of those that stabilize river banks. Grass roots grow concentrated and very tight, entwining themselves around and between sediment materials, thereby securing them and preventing river banks from crumbling easily. Unfortunately, however, grasses cannot always be relied upon to hold a river bank together because

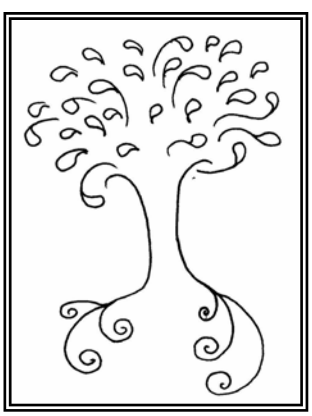
> **Phreatic** vegetation is vegetation that depends on ground water for survival.

their root systems often grow quite shallow. Trees on the other hand, have much deeper root systems so can usually support higher, steeper river banks (depending on the type of tree but we'll get to that in a moment).

It is important to note however, that there is no perfectly reliable individual root system. And while trees or woody types of vegetation may have deeper root systems they also tend to be looser and bigger root systems, in comparison to grass. Because of these traits, woody vegetation types are less able to hold finer sediment materials together. In this way, soils are often more likely to crumble away from around and in between the roots under pressure of flowing water. Also, river banks can collapse under the weight of trees.

Indigenous versus Exotic: does it matter?

In South Africa, there are many **exotic** species of vegetation growing all over the country as well as along river channels. An exotic species of plant or tree is one that is not naturally from South Africa, and therefore not compatible with the South African environment in a balanced way.



Exotic species can often overtake indigenous populations as they out-grow and smother local species; either by withdrawing large amounts of water for their own growth, or by growing and reproducing at a very fast rate. For example, exotic tree species often shade out certain grasses and plants that act as protective ground covers. In shading them out, the ground cover species can become weakened or die. For this reason, and because of their root systems, exotic woody species are often associated with eroding river channels.

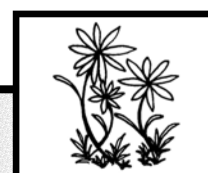
Indigenous species on the other hand, are local species that are suited to South African climatic, geologic and landscape conditions – indigenous species are part of the natural state of equilibrium that was mentioned earlier. In converse to exotic species, indigenous species normally form part of a more mixed plant community that has a balance of tree, shrub and ground cover.

Overgrowth of exotic species can compromise the growth of indigenous species. This can be harmful to the South African landscape and river banks are a prime example. Let's compare an indigenous fig tree to an exotic Australian wattle to illustrate this point:

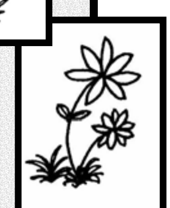
A fig is an indigenous species of tree that has wide, thick roots which permeate the soil deeply. When a fig grows on a river bank it will grow large, tall and wide – in a game reserve, you might catch a leopard lounging on one of its enormous branches. Because of their extensive root systems and the way that they grow, fig trees are able to withstand flood waters to a large degree and thereby contribute to river bank stability.
In comparison, the wattle tree is an exotic species from Australia that grows and spreads quickly in South Africa's climatic conditions. It has a

shallow root system, and its ideal habitat is along river banks. Often, this exotic species competes with other types of indigenous vegetation for sunlight and water. Unlike fig trees, wattles are less stable due to their root systems and tend to fall over easily. This adds more debris and woody material to a river channel, which causes it to widen due to increased vulnerability to erosion. Exotic wattles are unable to withstand flooding events to the degree of indigenous fig trees and thereby cause instability to banks in the areas where they grow. Generally, indigenous species of vegetation will uphold river banks and the riparian zone more efficiently than exotic species, plus they will use less water to grow - an important consideration with water being such a precious resource.

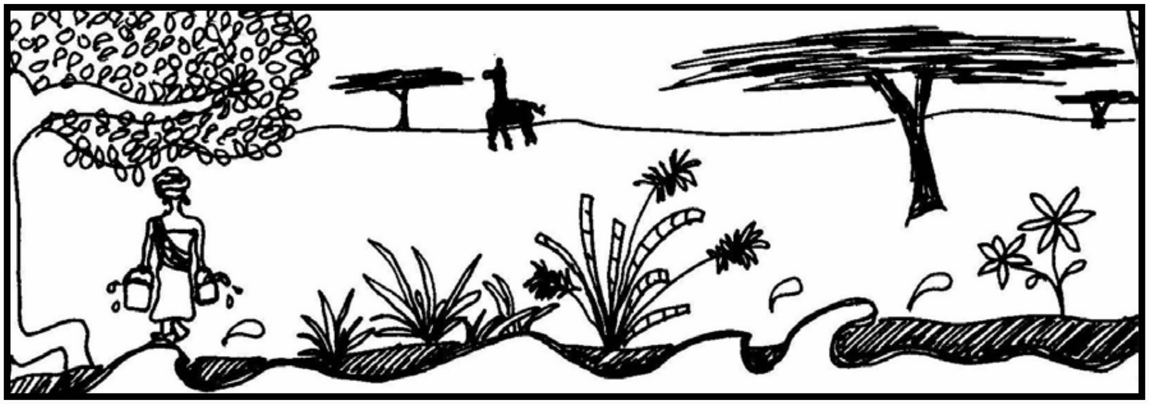
All of this information about rivers and vegetation is great to know, but what does it mean to geomorphologists? What does it mean to the average person? To river management? How does it help to know that the shape of a river channel is determined by catchment processes, flow rates, geology, sediment materials and vegetation growth; or that the components of a river environment are so interconnected that causing change to one component will cause change in all the other areas associated with it? What happens to this information at the end of the day? To start with, it gets classified.



Fluvial Geomorphology and River Rehabilitation



River rehabilitation is yet another concern for geomorphologists. **Rehabilitation** means to help restore something that has been changed, so that it can be much like it used to be. One of the challenges of river rehabilitation in South Africa is to help restore the riparian vegetation in areas that have been damaged by human influences like over grazing, over chopping of trees, or water depravation or inundation from a water management scheme



Why People Need Good Geomorphology

Natural Resources:
a River's Goods and Services

Some of the resources that a river provides and that we use every day are:

Fresh Water: For drinking, cleaning, cooking and washing; for the survival of our livestock/animals; to grow crops, herbs and plants. Many of the critters that live among the rocks in rivers help to keep the river water clean.

Food: The fish in a river can provide food for many generations of people, if the river is taken care of and kept clean. Fish need good habitat in the form of pools and riffles to survive and proliferate.

Wood/Building Materials: The trees, grasses and shrubbery that depend upon river water are used for medicinal purposes, as building materials and as shelter. These plants grow in the riparian zone.

Recreation: A river contributes to a wonderful natural environment where recreational activities. Swimming, walking, picnics, hiking and canoeing are a few good examples. Deep pools are good for swimming.

Quality of water can be the difference
between life and death – for everything.

Time, Space and the Classification of Rivers

The interesting thing about the characteristics/components of a river environment is that they experience change at different rates of time. One aspect of a river environment might change within minutes of a flow regime being altered, but another might take many months or even years to change. This is why geomorphologists need to study everything that makes up a river environment; *so that they can understand how all of the components relate to each other and how the components, in turn, experience change*.

As geomorphologists learn more about the characteristics of individual river channels, they become better able to classify those rivers. This allows them to make more accurate recommendations per channel in regards to water management schemes. In particular, they become better able to estimate how much water a particular river channel will need, in order to sustain a healthy environment.

Classification

To classify is to order or arrange objects or information into groups on the basis of their similarities or differences. Classifying rivers is important to geomorphologists because it helps them to understand the connections between the individual characteristics and the common features of different rivers.

Classification charts serve a number of important purposes. When features are named and put on a chart, they become a point of reference for other scientists that study the river environment. The terms, charts and scales, therefore, become a common ground for understanding. This is helpful because other scientific studies can then be compared to the ones that geomorphologists have done, and a more thorough or **holistic** and increasingly accurate report about a river system can result.

Let's look at an example of how, when fluvial geomorphologists and ecologists work together, they can create a more holistic study of a river environment. Let's also look at the role this type of holistic study can have in the development of water management schemes.

Geomorphologists study river systems; in particular their morphology and the morphological features that create habitats for living organisms. They also understand how change to a river system can cause morphological change which, in turn, influences habitat and living organisms.

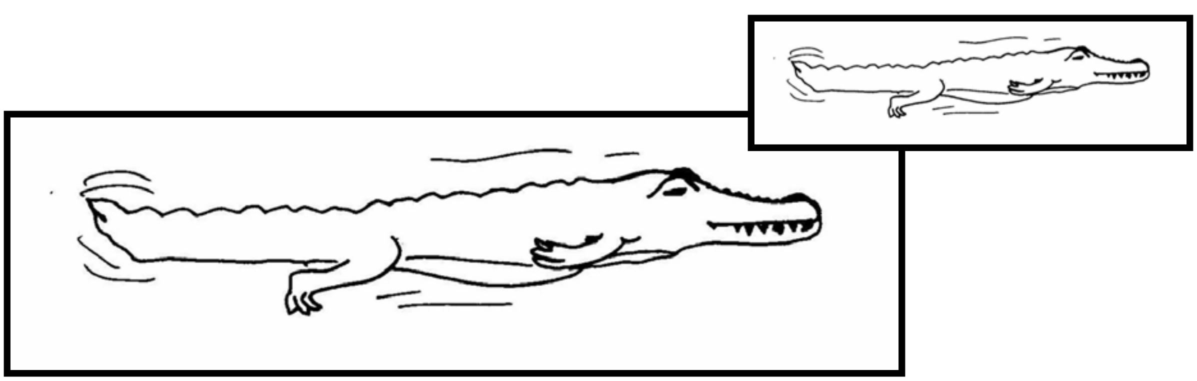
Ecologists, on the other hand, specialize in the *response* of organisms – noting how their lifecycles and survival depend upon and are influenced by morphological features and the components that make up a river environment. Together, these two groups of scientists can make a detailed holistic assessment about the potential and probable effects that a water management scheme can have on a river channel, in the context of a river system. These assessments can then be noted by water management scheme **engineers** (people that design the schemes)

> ***Did you know?***
>
> For a classification system to be successful it must be based on valid, legitimate and identifiable data. Which means you must be able to see that what the chart says is true.

and **managers** (people who manage water management schemes), and an effort can be made towards sustainable development of managed water ways. It is important then for fluvial geomorphologists, ecologists, engineers and managers to look to each other's expertise in order to help develop water management schemes that are sustainable for the environment and for people.

Geomorphologists, ecologists and river managers can work together to use river resources in a sustainable way. Enabling these three groups of professionals to understand each other is crucial to co-operative and successful interactions in this regard. And classification charts can be used as a common tool, whereby important information about a river system can be logged in a way that is comprehensible to all groups of river professionals. Such charts can help ensure that there is mutual understanding and recognition of what needs to be taken into consideration, in order to ensure the future sustainability of natural river systems.

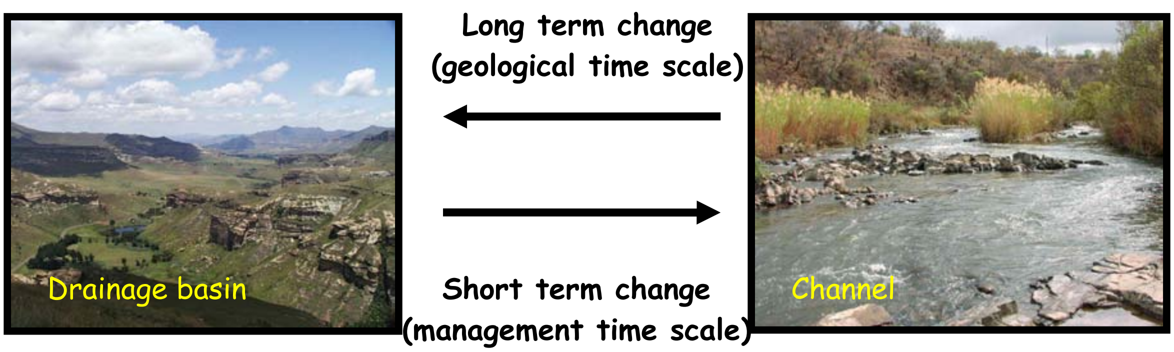
In order to classify information, geomorphologists first have to distinguish what is special, different, or similar about the characteristics of different river systems. Because they evaluate this information in relation to time and space scales, geomorphologists must also take time and space into consideration.



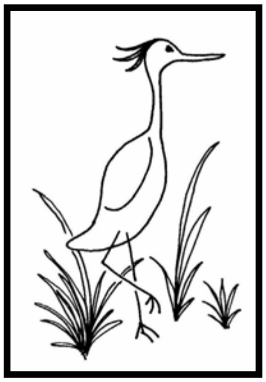
Time and Space Scales

<u>Diagram 9a</u>: Cause and Effect in Fluvial Geomorphology

Over the long term, erosion by the river creates the landscape of the drainage basin, but in the short term, the characteristics of the drainage basin determine what happens in the river channel.



Two very important considerations for river management come from geomorphology: one is **time,** and the other is **space**. This awareness of time and space scales is crucial to the sustainable development of water management schemes and must be noted within the context of the changing nature of a river environment. This means that managers must be mindful of how long it takes for geomorphological change to occur. They must also understand that change along a river channel and within a river system does not happen all at once. That is to say, one change might occur almost immediately at one point in a channel, while another, further away, might respond in a completely different manner over a longer period of time. It is for this reason that, when classifying our changing rivers, it is important to take into account scales of **time** (developments and changes over time) and **space** (developments and changes that take place at different scales within the river system).



Time Scales

The characteristics of river channels develop over three particular time scales: geological, geomorphological, and ecological.

The **geological timescale** refers to the time span of the geological history of the earth. It observes the landform changes associated with past eras and compares them with current landform conditions (i.e. since the Jurassic period, 140 million years or so, until now). The geological timescale goes all the way back to, and before, prehistoric times (when human kind first appeared on the Earth). Clearly, a geological timescale which spans millennia is outside the time frame of a contemporary river management scheme. Nonetheless, it provides important information for understanding modern river systems because it

A Holistic Approach

To consider something holistically is to consider how all of its parts affect each other and to study them, and their effects, simultaneously.

► Ecologists study the biological aspects of river ecosystems and their links to the river environment.
►Geomorphologists study how changes in flow and morphology affect the aspects of a river channel (including ecosystems) and shape that environment.
► Engineers design dams and extraction systems, actions that effect the flow and sediment regime of the river channel and thereby, the morphology.

If ecologists, geomorphologists and engineers all have a point of reference to work from, their work becomes synchronized. This benefits the river environment and all that make use of it.

maps what has “led up to now”. The development of an entire drainage basin, its river network and valley forms, takes place over the geological time scale.

The **geomorphological timescale** (measured in years to centuries), however, is far more current than the geological timescale and is looked at as the period of time in which the state of “equilibrium” is reached in river processes and channel geomorphology. It is also the time scale over which a channel responds to engineering developments that affect the flow and sediment regime. At the geomorphological time scale, changes in riparian and aquatic habitat occur due to changes in channel morphology. This is the timescale given significant consideration in river management schemes because it is “recent” in comparison to the geological time scale.

The **ecological timescale** (measured in hours to days) is considered in tandem with the geomorphological timescale because it recognizes immediate changes to habitats and ecosystems caused by variations in flow and sediment through the channel. At the ecological timescale geomorphology is considered stable, while ecological factors are

Did you know?

Sustainable development means to use a resource wisely, while it is being developed. Examples of sustainable development in our every day lives would be: using some trees to build or for firewood, but leaving some behind for future use; using some water for development, but leaving enough behind to ensure that the area where the water comes from doesn’t suffer irreparable damage from the loss; using water from the river to wash clothes but being sure not to leave soap boxes or other forms of garbage in the river that might pollute it, especially because others may be using river water for drinking water.

Sustainable development means to think about the future and consequences.

considered highly susceptible to alterations caused by changes in flow. The ecological timescale provides the framework within which much data is collected and many processes observed. It is the most immediate of the working time scales and therefore the most readily conceptualized by researchers and river managers (largely because the results/changes often occur immediately, and are therefore evident to the naked eye – making them tangible). It is also within this time scale that geomorphological research combines, in a most excellent manner, with the skills of other scientists. Their combined efforts offer a more accurate, holistic and scientific basket of advice for effective river management, assessment or rehabilitation

Space Scales

Spatial scales describe and classify how different morphological characteristics, located at different points along a river channel, respond to change. "Space" means location, and spatial scales question and link location with rates of change.

The concept of spatial scales relates directly to a type of hierarchy, i.e. a catchment being a large scale feature and a rock pool being a small scale feature. The following is an example of how these scales link to time scales: The geomorphology of a catchment (hillslopes, valley form, drainage network etc.) and the long profile of a river change over a very long time scale (geological time), whereas the

> ***Did you know?***
>
> Together, **time** and **space scales** determine how change in a river system evolves – and help us understand how river channels came to be and where they are going in the future.

shape of a channel can change over the geomorphological time scale (10-100 years); this can be compared to the variations in depth and velocity that change as discharge changes – instantaneously – it is these **hydraulic** characteristics that determine the habitat for the fish, crabs and small insects that live in the water. There is a clear correlation between noting the time and space scales of change in a river system. And both must be noted in order to gauge how imposed changes will affect a river environment and all of its components, in the short term and in the long term. Diagram 9b should help put all of this into perspective.

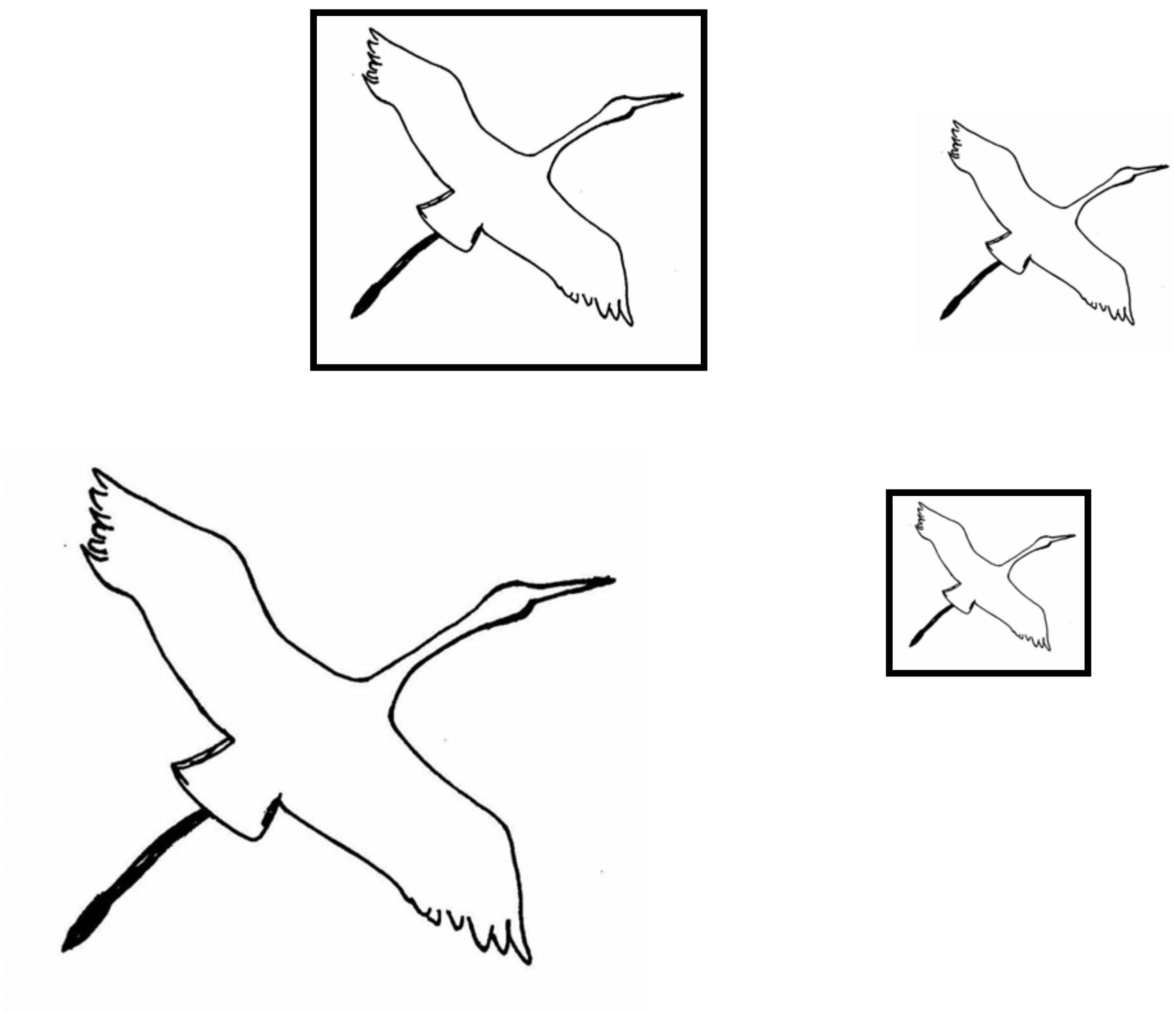
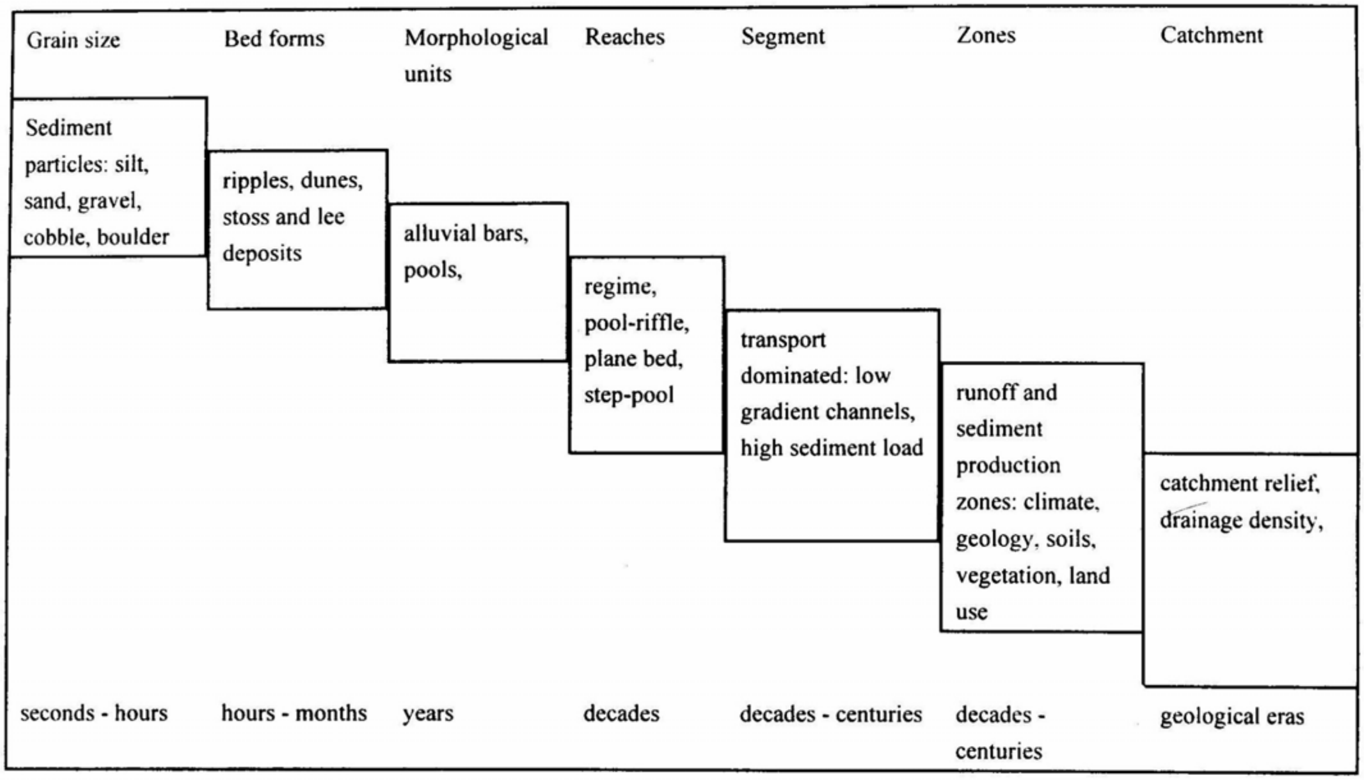
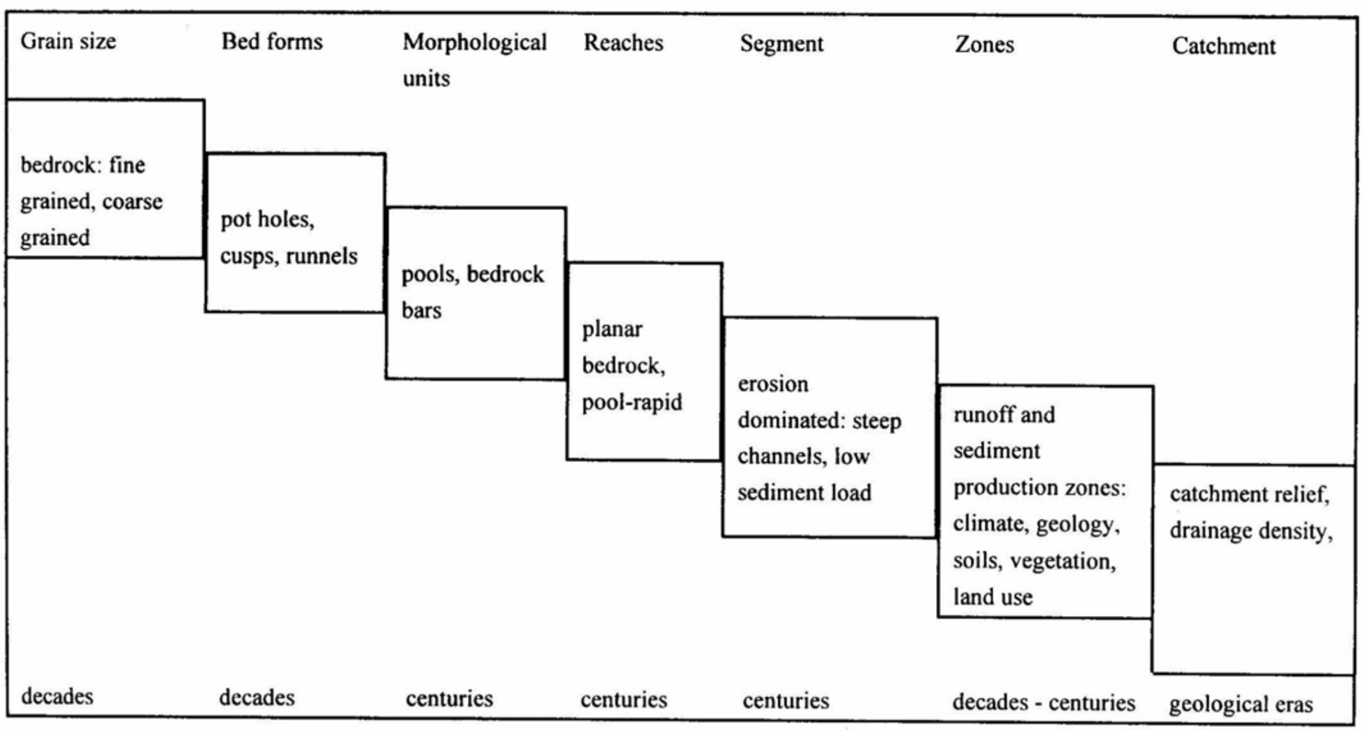


Diagram 9b: Time – Space relationships in alluvial and bedrock systems



a) Time-Space relationships in alluvial systems



b) Time - Space relationships in bedrock systems

Classifying Rivers and Their Components

Time and space scales also indicate dependency relationships within a river system; for example, in the geomorphological time scale, channel form is dependent on the discharge and sediment regime.
Another example: Within the ecological time scale, geomorphologists consider that channel form remains stable but that the characteristics of flow (in terms of hydraulic variables such as depth and velocity) change as discharge changes. This change, however, will also depend upon the shape of the channel; for example, the same discharge in a wide channel will have lower depths than if it flows down a narrow, deep channel. Also, as discharge increases, depth and velocity will increase in both channels but at different rates. So *who cares*? Well, these exact types of dependency relationships are found throughout every single river system, and aquatic life must adapt to these patterns. Therefore, it is important to know about dependency relationships if sustainable river management schemes are going to be developed successfully. It is for all of these reasons that time and space scales are always considered together in geomorphological studies.
Take a look at Diagram 10a – for a good example of how river system characteristics and components are laid out over time and space scales.

Together the flow and sediment regime, although reliant on catchment processes, define the morphology of a river channel.

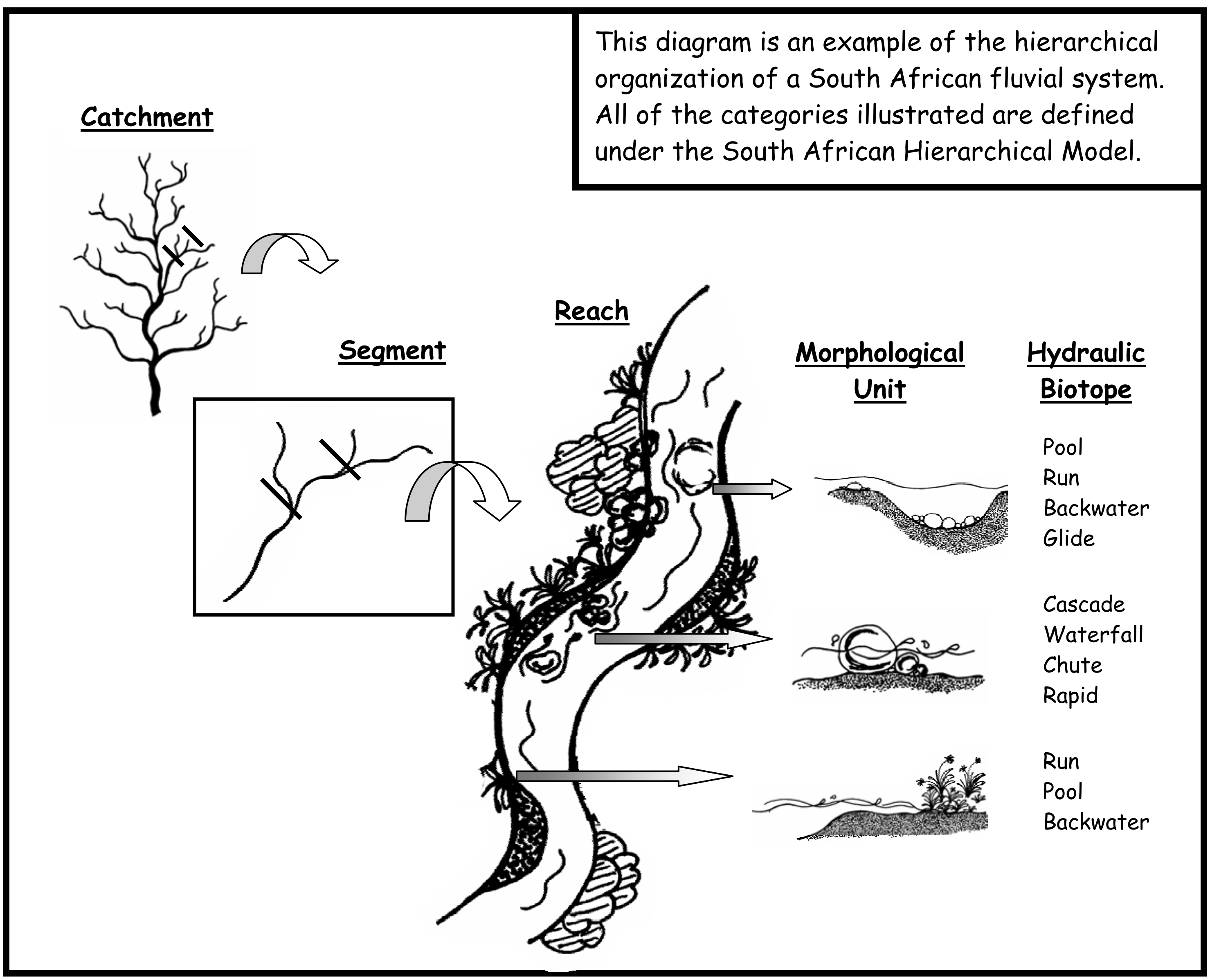





A Hierarchical Geomorphological Model

Hierarchical classifications lay out river system data in a cascading form by classifying characteristics in the order that they influence each other. This system of classification identifies dependency relationships between all aspects of a river system and classifies them hierarchically, i.e. from the top, a system at one level is said to determine the characteristics of the lower levels. The same system can also be used in a bottom up fashion.

Diagram 10a



The concept of hierarchical classification is used as a basis for the classification of South African rivers, and as a tool for river management. **The South African Hierarchical Model** has five levels: the Catchment, the Stream Segment, the Reach, the Morphological Unit and the Hydraulic Biotope. It is a cascading system in which each level provides input for the one below it. The framework of the model provides a charted link between the channel and the catchment, and accounts for catchment activities. The model also provides a structured description of spatial variation of instream habitats, thus giving a framework that identifies where physical features change and develop, and identifying what that has to do with the flow and sediment regime.

> *The hierarchical framework for river classification provides a scale based link between the river channel and the catchment, so as to account for catchment dynamics.*

The most obvious benefit of a hierarchical model is that it provides a common system for the description of streams at various scales. In this way, it facilitates the comparison of numerous variables within and/or between similar systems. This allows for more solid classification and stable reference points and terms when comparing different river systems.

The South African Hierarchical Model is divided into two main sections: Aerial Features, which relate to the catchment surface, and the actual Channel Features that constitute the drainage network.

Aerial Features – The Catchment

As mentioned earlier in Aspects of a River Environment, the catchment is the land surface that contributes water and sediment to any given stream network.

Catchment Hierarchies

It is interesting to note that catchments also have their own hierarchy. This is because river systems are composed of several catchments of increasing size, draining one into the other. The following diagram is an example of this:

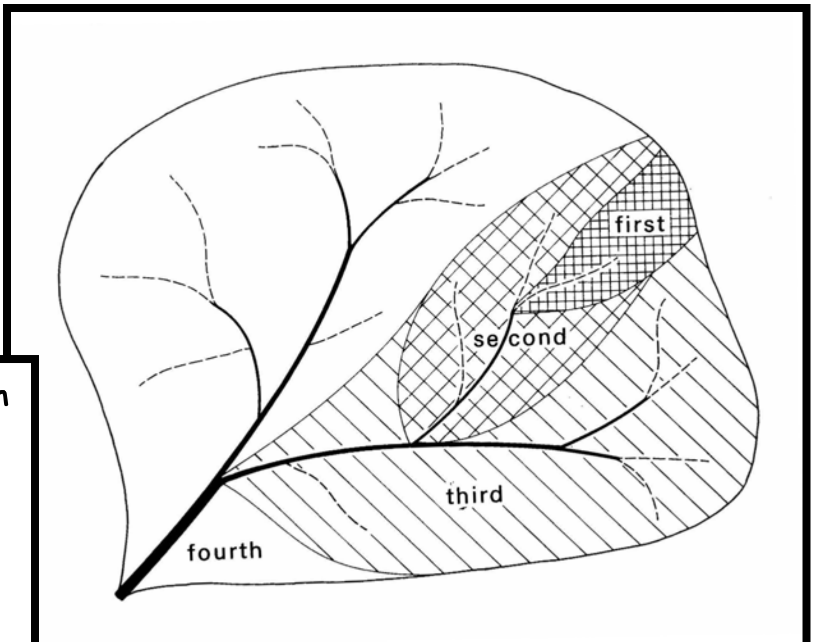


Diagram 10b: The diagram to the right, illustrates how streams feed into streams to eventually becomes rivers. Note how the catchments are divided into sections. This helps with classification.

The smallest catchments, containing one branch of the channel, are known as first order catchments. When two first order streams join they become second order, and the total area that these streams drain is a second order catchment. The second order catchment shown on the diagram contains three first order catchments. Can you identify these? Second order streams join up to form third order and so on. As you can see, the first order catchment feeds into (and is part of) the second order catchment, the second order feeds into the third and the third order feeds into the fourth. If geomorphologists want to know where water and sediment is coming from at any point along a river channel, they must look at the whole catchment above it, especially the small catchments of the first order channels, as together these make up a large percentage of the greater catchment area.

First order catchments, being small in size, are generally quite homogenous in the characteristics that affect runoff and sediment yield. These include the steepness of the hillslopes, the underlying geology, and soils and vegetation. It is not too difficult to group or classify a first order stream according to these characteristics. As the stream order increases and the catchments get bigger their characteristics become more and more diverse, which makes classification more difficult. Ultimately, each river system is a unique combination of different features, and attempts to classify large catchments can prove to be a difficult and fruitless task. Dr. Mud says, “In these cases, geomorphologists need to look at the structure of the drainage network and its relationship to the spatial distribution of catchment features. They can do this by applying the hierarchical model to the channel network that they are studying.”

The Stream Segment

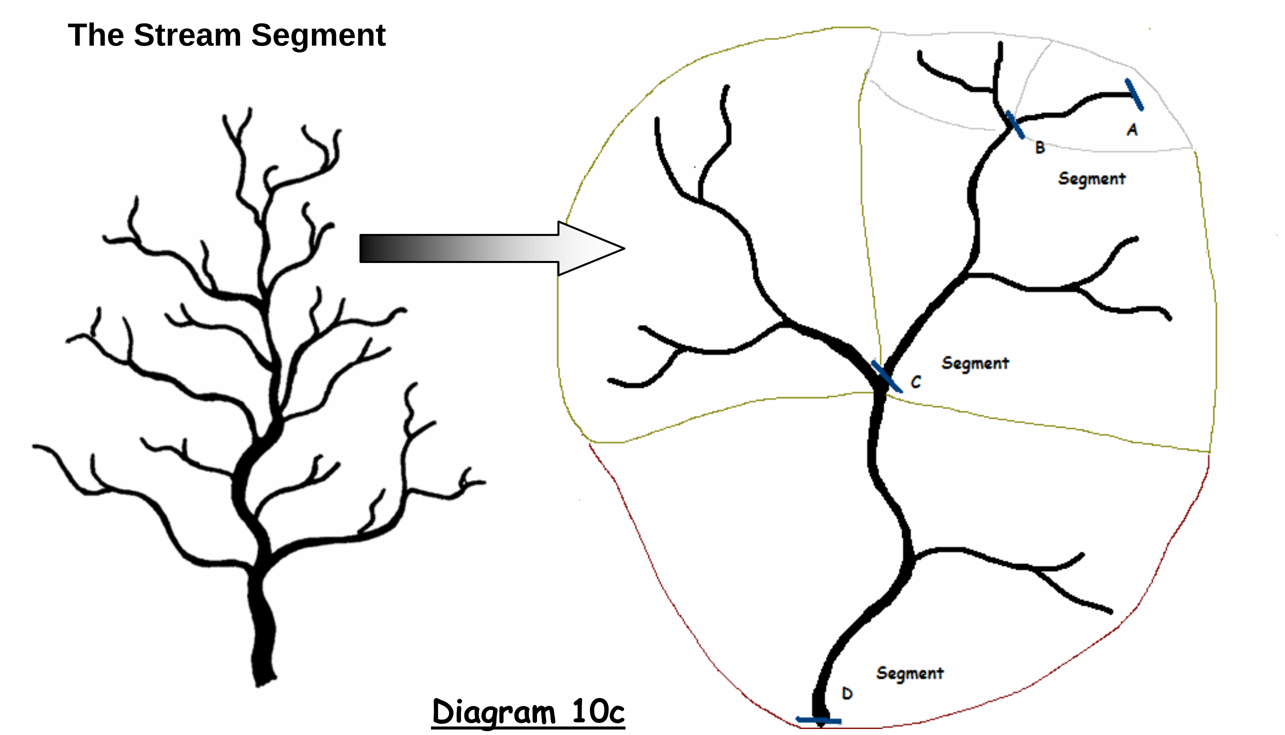


Diagram 10c

The Stream Segment

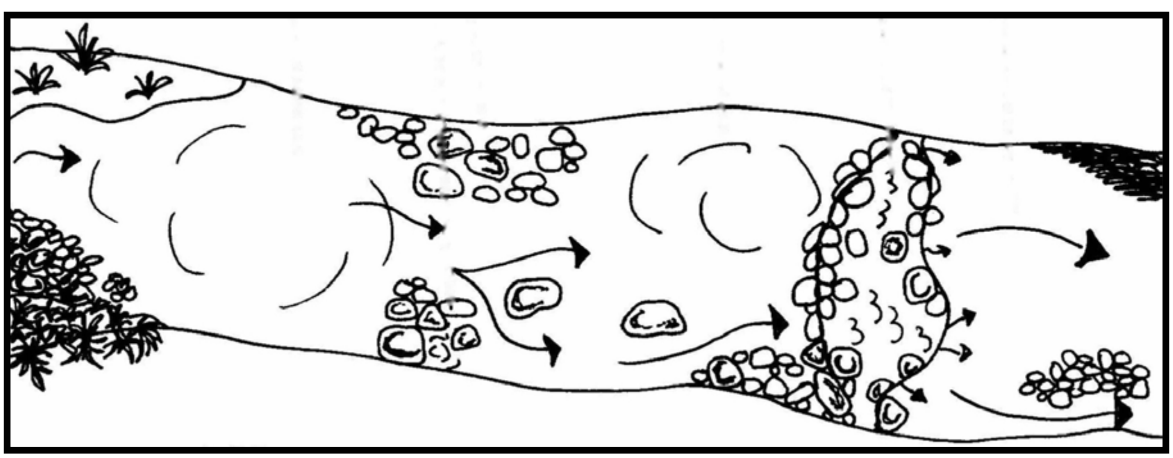
In Diagram 10c, one of the river channels has been divided into segments from its source to its lower regions. We can see, as we progress from the fingertips of the streams, down the system, that the catchment area gets progressively larger. But at certain points, where another channel of similar size joins the main channel, the catchment suddenly becomes much larger. This occurs at the two points, B and C. This means that at these points the amount of water and sediment moving through the channel will suddenly become much greater. It could therefore be expected that the channel would respond by changing its characteristics. Such significant changes in channel inputs are used to identify what geomorphologists term, **segments**.

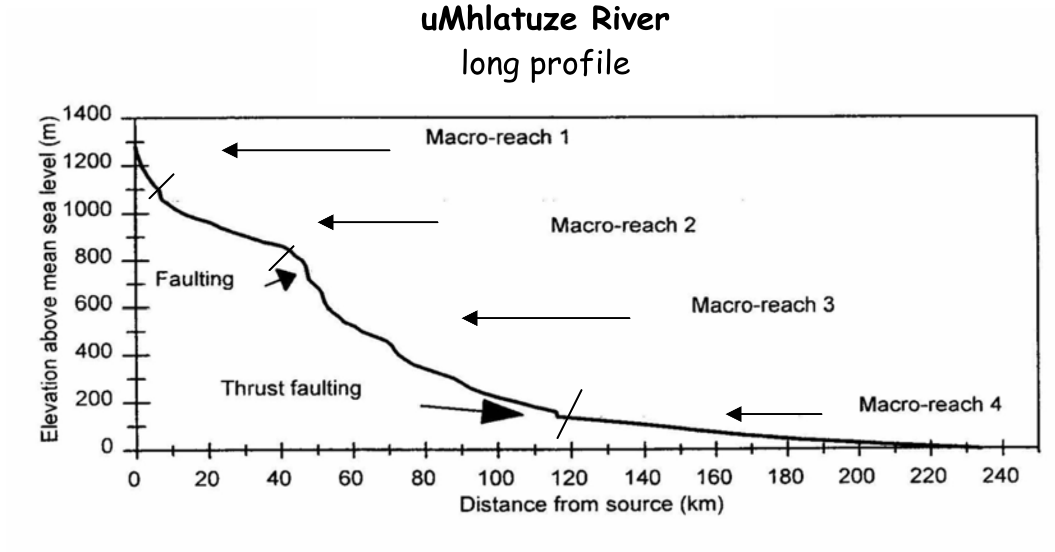
> **If channel segments are uniform, it means that they have similar characteristics.**

A segment is a length of channel along which flow discharge and sediment load are fairly constant. What this means is that there is no significant change in the volume/amount of flow, and no significant change in how much sediment is delivered to the channel from the hillslopes or tributaries. In one segment, the inputs to the river channel are similar along the segment's length, but what happens to these inputs may change depending on other factors such as the gradient of the channel, or the shape of the valley through which the river flows. In order to understand how a river responds to these downstream changes in flow and sediment, geomorphologists need to look at the river long profile and its associated reaches.

The Reach & the River Long Profile

A **river long profile** shows how the gradient of a river channel changes along its entire length. The long profile is divided into lengths of channels that have the same gradient. These areas are called "reaches". To simplify the description of a long profile, reaches are often grouped into broad zones of similar gradient know as *macro-reaches* or *zones*. See Diagram 10d as an example of these reach divisions.





<u>Diagram 10d</u>: The sample diagram of the uMhlatuze river long profile illustrates the designation of Reaches in comparison to gradient changes

As a general rule, changes in gradient down the length of a river are reflected by changes in channel characteristics. Reaches commonly display certain bed material characteristics that relate to gradient. For example, coarse sediment types like boulders and cobblestones dominate high gradient reaches, whereas the percentage of gravel and sand increases as gradient is lowered and fine materials are more likely to be deposited. A mountain stream would therefore be characterized by steep channels with bedrock, boulders or cobbles making up the stream bed. But as that same stream reaches a foothill region, the channel gradient decreases, and gravels and increasingly finer sediment types begin to dominate. By the time the gradient decreases into the lowland reaches of the channel, sandy sediments will probably characterize the river bed.

These more or less regular changes down the long profile of a river have often been classed according to the table below. These zones are also accepted by ecologists as being closely related to ecosystem changes down a river long profile.

<u>Diagram 10e:</u> Geomorphological Zonation of River Channels

Zone	Gradient class	Characteristic channel features
Source zone	not specified	Low gradient, upland plateau or upland basin able to store water. Spongy or peaty hydromorphic soils.
Mountain headwater stream	> 0.1	A very steep gradient stream dominated by vertical flow over bedrock with waterfalls and plunge pools. Normally first or second order. Reach types include bedrock fall and cascades.
Mountain stream	0.04 - 0.099	Steep gradient stream dominated by bedrock and boulders, locally cobble or coarse gravels in pools. Reach types include cascades, bedrock fall, step-pool, approximate equal distribution of 'vertical' and 'horizontal' flow components.
Transitional	0.02 - 0.039	Moderately steep stream dominated by bedrock or boulder. Reach types include plain-bed, pool-rapid or pool riffle. Confined or semi-confined valley floor with limited flood plain development.
Upper foothills	0.005 - 0.019	Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plain-bed, pool-riffle or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow flood plain of sand, gravel or cobble often present.
Lower foothills	0.001 - 0.005	Lower gradient mixed bed alluvial channel with sand and gravel dominating the bed, locally may be bedrock controlled. Reach types typically include pool-riffle or pool-rapid, sand bars common in pools. Pools of significantly greater extent than rapids or riffles. Floodplain often present.
Lowland river	0.0001-0.0009	Low gradient alluvial fine bed channel, typically regime reach type. May be confined, but fully developed meandering pattern within a distinct flood plain develops in unconfined reaches where there is an increased silt content in bed or banks.

An important characteristic of many South African rivers is that their lower reaches do not follow the above trend of reduced gradients. Rather, uplift due to geological processes over the last fifteen million years has caused rivers, such as those flowing off the Drakensberg escarpment, to cut steep courses through deep gorges. A good example of such a river is the Mgeni below Howick Falls. A trip to the bottom of the Valley of the Thousand Hills would reveal a boulder bedded river flowing through a steep gorge. Landslides on these steep hillsides deliver boulders and other sediment materials into the channel, just as would happen in mountain areas.

A More Detailed Classification of Reaches

Within each zone, reaches can take on a number of different characteristics. How these characteristics develop depends on many things such as: channel gradient, valley shape, the rate at which sediment is supplied to the channel, size and type of sediment, the underlying geology of the region, and riparian vegetation.

These factors influence everything about how a river develops. Does it meander? Does the channel divide into a number of separate branches? What is the shape of the river? Is it wide and shallow or deep and narrow? What is the type and arrangement of features within the channel itself? Are there a series of rock pools? Are rapids a common feature? All of these features can be used to describe and group reaches into similar

Did You Know?

Ecological developments within a river system (i.e. plant and animal habitats) rely heavily on the presence of water, but they also depend largely upon the morphology of the channel. Things such as over hanging banks, large sandy beaches, cobblestones, and depth are but a few examples of morphology that influences ecological development.

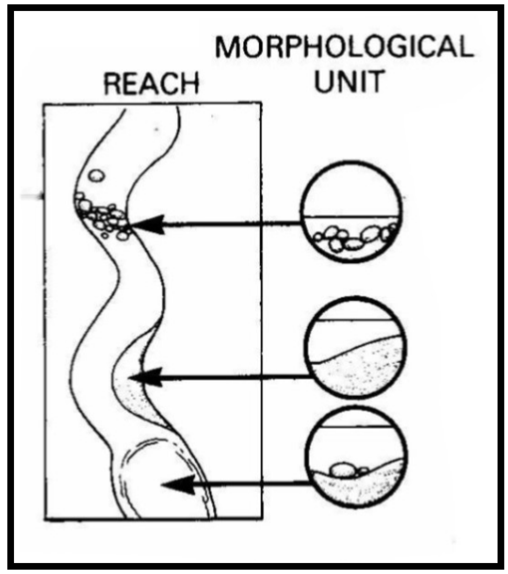
Ecological features can also depend on how fast river water flows which, ultimately, depends again on the morphology of the channel.

types. Refer back to the diagrams on page 17 to review the some of the different ways that river channels can form.

The delineation of reaches and their initial classification can be done from topographic maps. By looking carefully at the contours in relation to the line of a river, geomorphologists can calculate the gradient of a channel and visualise its valley form. For example, they can distinguish steep sided valleys confining a channel to a narrow valley bottom from valleys with a broad flood plain across which a river can migrate. They can also differentiate meandering channels from straight channels, or channels with large islands. To classify reaches further, however, they need to get into the field and examine bed material, channel shape or morphology, and other important factors such as the nature of the channel's riparian vegetation. The final classification of a reach is carried out in the field once the **morphological units** have been identified. Morphological units form the next level of the South African Hierarchical Model.

The Morphological Unit & Morphological Classification

Morphological units **are the basic structures** recognized by fluvial geomorphologists as **making up river channel morphology**. If you were to take a single reach and study it in detail you will find that the reach is made up of a number of different morphological units that are arranged along and across the channel. These may include various sorts of pools, rapids or riffles (these are types of hydraulic biotopes which are explained further in the next section), cobble bars along the edge of the channel, and even the flood plain itself.

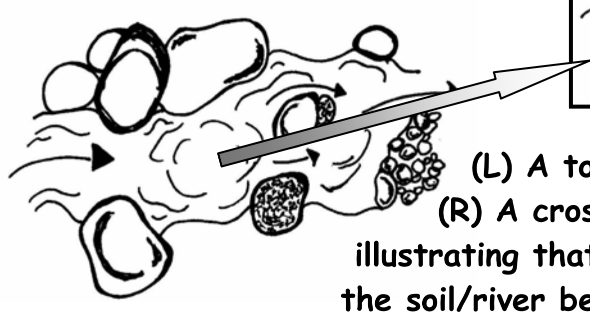


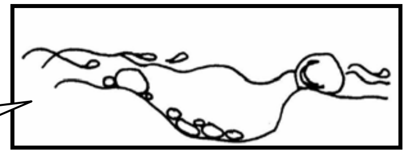
Morphological units within a river channel form in response to different flows and sediments that move through the channel over the long term. Unless an extreme flood comes through the system, or large amounts of sediment are dumped into the channel (perhaps as the result of a landslide) morphological units are unlikely to change from one flood event to the next. As a flood subsides, morphological units can be seen to control the characteristics of low flows within a channel, i.e. influencing flow rates or flow routes.

Morphological units are identified as being either erosional or depositional features. **Erosional features** are formed by the removal of material by the action of water. Waterfalls and pools are examples of erosional features.

Depositional features are formed by the deposition of sediment materials carried into the reach from upstream. Gravel riffles, sand bars that form islands in the middle of a channel, and flood plains are all examples of depositional features. Together, erosional and depositional features make up the morphology of a river channel.

Diagram 11a



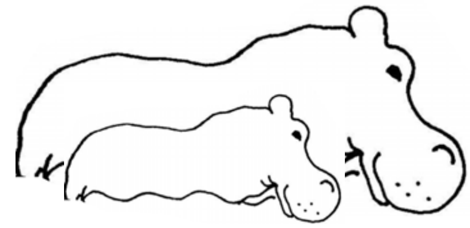


(L) A top view of a "pool" morphological unit. (R) A cross-sectional view of that same pool, illustrating that a pool is an erosional feature as the soil/river bed/sediment has eroded in order to allow the pool to form.

Irregularities in a channel, such as meanders, bars, or islands cause eddies to form with fast swirling water and quiet backwaters. Morphological units, therefore, play an important role in determining the flow environments experienced by organisms living in or on the edge of the flow. Morphological units also determine the type of material that forms the substrate on which plants and animals live. They are, therefore, key determinants of aquatic and riparian habitat.

Feeling overloaded with new information? Let's take a bit of a break to find out about how morphological and ecological features influence each other. No pressure, just keep your eye out for crocodiles and hippos. Grab a tube and let's head for the uMhlatuze!

Morphological Classification & Hippos



Morphological classification looks directly at how morphology influences a river environment: in particular, how morphology can influence ecological features. Specifically, morphological classification links the morphological and ecological features of a reach, in order to determine how they influence each other. For example, how do different types of sediment influence variations in ecosystem development?

It is at the level of the Reach that the strongest links are thought to exist between geomorphology and ecological function. This is because **channel morphology provides the physical structure that determines habitat conditions.** The story of *The Dam as a Hippo* in Nkwaleni Valley is a good example of this.

The Dam as a Hippo:

hypothesizing ecological and morphological links
through farmers testimony

In the early 19th century, boats cruised up and down the uMhlatuze River. At that time, the river was home to many hippos and crocodiles but as additional farms (and humans) moved in, changes were made to the uMhlatuze area and its surrounding environment (e.g. Nkwaleni Valley) to accommodate human development. These changes included shooting out hippo and crocodile populations that might threaten human safety and prosperity. All of the hippos disappeared and most of the crocodiles were killed as well, those that survived couldn't have stayed if they wanted to because after the hippos were gone, the uMhlatuze in the Nkwaleni Valley began to change.

As the seasons passed, the channel through the Nkwaleni valley changed even more for the remaining crocodiles. Where the hippo used to wallow and create pools there were none, and when winter seasons came and the uMhlatuze ran dry, there was no place for crocodiles to find refuge. Where the hippo used to barge their way through vegetation and widen the channel, there was now encroachment and narrowing which, coupled with an increase in sediment (development of surrounding areas increased erosion), created a less than ideal habitat for remaining crocodiles to live and reproduce.

Those crocodiles that remained in the uMhlatuze had to leave the Nkwaleni Valley or suffer the same fate of their larger, co-habitants – death by bullet. When Leroy du Preez was growing up, there wasn't a croc to be seen.

And then the Dam was built…

When the Goedetrouw dam was built, it caused geomorphological changes in the uMhlatuze which, in turn, led to ecological changes that have once again encouraged a crocodile friendly habitat. Here's how:

After the dam was built, there were no longer any drastic fluctuations in water levels. The uMhlatuze never ran dry because the dam created constant flow (remember how happy this keeps Percy Smith?). The uMhlatuze also became deeper with the building of Goedetrouw, as the dam wall blocked sediment from coming downstream and the constant flow of water began to remove old sediment build up. A deeper channel and permanent water re-created a permanent habitat for crocodiles.

So how does this make the dam a hippo? Well, it is a general comparison in reference to the role of hippopotami in changing the morphology of a river so that it is crocodile friendly. When the hippo were shot out the morphology of the uMhlatuze altered, making the habitat less than ideal for crocodiles. Now, with the dam, the morphology of the river has changed again, the water flow is constant and it is deeper in places due to changes that the dam has caused in the sediment regime of the river. The dam has influenced crocodile friendly morphological and ecological changes in the Nkwaleni Valley, just as the hippos used to in the early 1900s.

All of the information in "The Dam as a Hippo" story came from the testimony of farmers who have experienced and in some cases documented the geomorphological and ecological changes of the uMhlatuze over the years. Can you identify which river features would be ecological and which would be geomorphological? Can you see how using the two sciences together helps to create a full picture of what change means to a river system, and how geomorphological and ecological research are linked – just like hippos, crocodiles, geomorphology and habitat?

Did you also notice how the farmer's testimony became a living "history text" about the uMhlatuze river?

Without even knowing it, the farmers offered information that could help scientists piece together the general health history of the uMhlatuze River; thereby helping them work towards an efficient water management scheme. By studying the changing morphological and ecological features together, how change effects change along the banks of the uMhlatuze becomes much clearer.

…Now, let's get back to learning about the final level in the South African Hierarchical Model: the Hydraulic Biotope!

Hydraulic Biotopes

Morphological units are relatively stable features that are made up of either sediment deposits or solid bedrock. Although shaped by water, these units remain whether a river is in flood or whether it has dried out during a drought. It is important to note that while the morphological unit may stay the same during all of these changes, the sort of habitat that is found in the river varies greatly between such extreme variations in flow (including variations caused by seasonal flow changes).

> **Remember:**
> ***hydraulic***
> **means**
> **"controlled by water"**

For organisms that live within the flow, the key determinants of habitat are the material on the bed of the river, the velocity of the water, and the depth of the water. These determinants are used to define **hydraulic biotopes** which are small scale "environments" that support certain components of an ecosystem. Hydraulic biotopes are can be altered completely by changes in flow or by movement of sediment materials; but we will learn more about that in a moment.

What we have learned so far is that with variations in flow, only bed material remains more or less constant; this is because velocity and depth are highly sensitive to flow rates/discharge. As discharge increases, depth and velocity increase as well, but the rate at which these changes take place depends upon channel morphology.

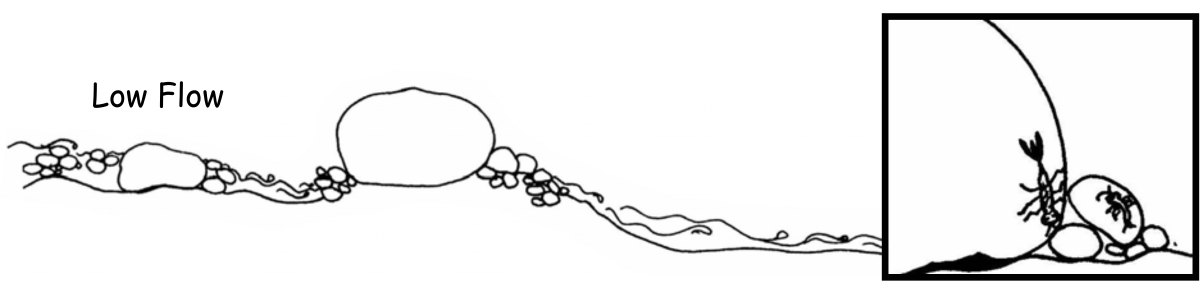
A bit more detail…

A hydraulic biotope is a small patch in a river that provides, at any one moment in time, a more or less uniform (remember, *uniform* means "the same" or "consistent") flow environment to the community of organisms living within it. Key flow variables used to characterize a hydraulic biotope include the depth of flow, its velocity, and other related hydraulic variables, as well as the size and arrangement of material on the bed.

Hundreds, if not thousands of small hydraulic biotopes can be found in rivers and streams from the upper reaches to the river mouth; each hydraulic biotope provides different types of habitats for the aquatic species living in them (see Diagram 12a).

The next time you are beside a river at low flows, find a section where the gravels, cobbles or boulders are close to or break the surface. This will almost certainly be the type of hydraulic biotope that is called a "riffle" (if coarse gravel) or rapid (if boulder). Now look at the characteristic of the flow. You will probably see some white water where the flow is "broken" by the underlying material, as well as areas where the flow forms small waves on the surface; areas where the flow is clearly moving quite fast but has a rippled or smooth surface; and other areas still, where the water is sitting in small pools behind boulders or in shallow areas among cobbles. You will now understand that the one morphological unit – a riffle or rapid – contains many patches of different types of flow, and that each of these "flow types" represents a different combination of depth and velocity; as well as a different habitat. If the water is relatively deep, the water surface remains smooth or glassy. As velocity increases relative to depth, the water surface becomes rippled, then waves start to form and eventually the waves break to give white water. Patches of different **flow types** can be used to distinguish different flow habitats and, when combined with the underlying bed material, are used to define the different **hydraulic biotopes**.

Diagram 12a: How hydraulic biotopes form depends on the shape of sediment materials, and on the flow regime of the river channel. When flow rates (velocity and depth) change, so does habitat.



Now that you have identified your riffle or rapid, go and look at the pool upstream or downstream of it. What does the water surface look like there? How many hydraulic biotopes can you identify? At low flows the pool will be dominated by large areas or deep slow moving water, but you may see some areas where the water is moving quite fast, albeit with a smooth surface. So, even in a pool we can find more that one hydraulic biotope, but they tend to be larger and less complex than in a riffle or rapid.

What if you were to come back to that same point in the river at another time when the flow levels were different? Maybe the flow would have dropped after a long dry spell, or a storm may have caused water levels to rise. Think about what might happen to the hydraulic biotopes in those conditions. Almost certainly they will have changed. In the riffle, a drop in flow would result in less white water and an increase in shallow pools along the margins. There would also be an overall loss of depth, and the water would occupy a smaller area of the channel. In the pool, the main change would probably be to velocity. Lower velocities mean that there would be less of the fast smooth flow. These flow dependent changes illustrate the sensitivity of hydraulic biotopes to flow changes. Because of this, hydraulic biotopes are regarded in the ecological timescale.

Hydraulic biotopes are important to river research because they provide the link between the physical (geomorphological) and the ecological components of a river system. They are the evidence of how ecological

Fast Facts

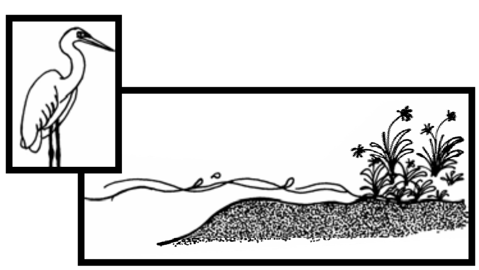
- Catchments are the source areas for water runoff and sediment
- Water and sediment are routed through river channel networks
- River channel networks can be subdivided into segments and reaches
- Reaches are described in terms of morphological units and their associated hydraulic biotopes

relationships depend on the structure of a river channel and the water that flows through it. A useful feature of hydraulic biotopes is that they can be mapped for different levels of flow. These maps are useful indicators of available habitat, and play an important part in determining ecological water requirements – that is, the amount of water that is required to sustain river ecosystems.

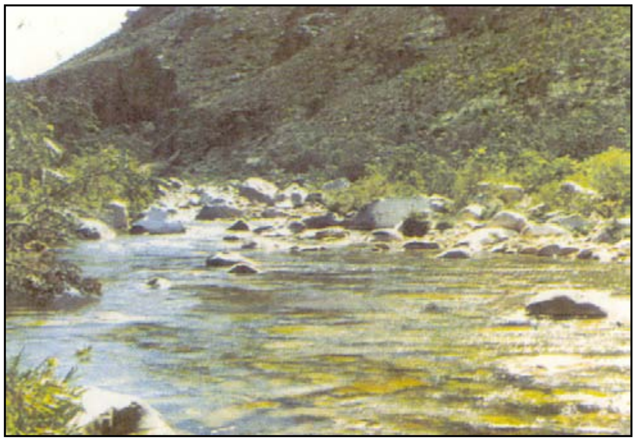
Defining & Classifying Hydraulic Biotopes

Developing the terms and definitions for hydraulic biotopes was no easy task. Geomorphologists found that while most river researchers intuitively recognized the existence of hydraulic biotopes, there was little synchronicity of terminology and definitions. It was discovered that many researchers were using their own terms and individual definitions to define various hydraulic biotopes. Clearly, all of these different definitions did not suit the goal of classification, which is to establish commonly understood definitions that can be referred to by many (such charts can be added to and changed as more information is discovered).

In order to move forward with the South African Hierarchical Model, geomorphologists and ecologists needed to come together to toss around terms and agree on definitions and identifying features. Diagrams 12 b-e are a few examples of hydraulic biotopes according to the definitions agreed upon by river science professionals with pictures of what they would look like in a river system.



Diagrams 12b-e

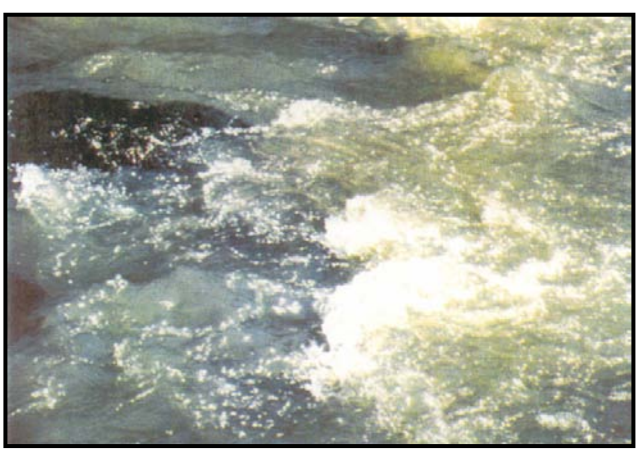


Run

A run has rippled flow, with no broken water on the surface. It is found with any type of substrate and where there is no obvious change in streambed gradient.

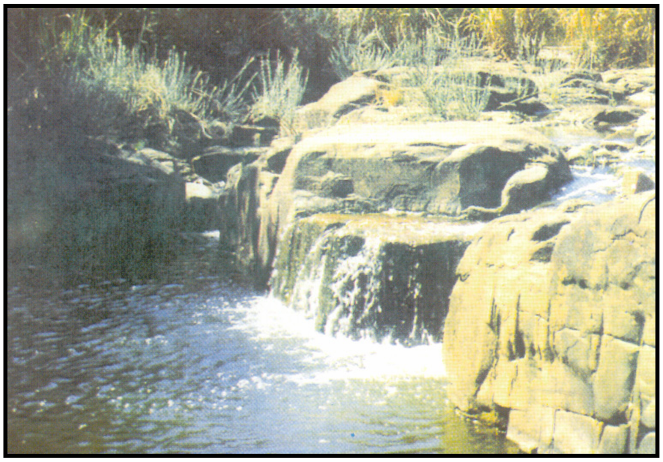
Riffle

Riffles are wavy spots that form over coarse alluvial substrates like gravel and cobbles. The waves look like they are standing still as the water flows over the rocks, sometimes the surface of the water simply undulates, other times the water breaks at the surface.



Cascade

A cascade has a free falling flow over a substrate of boulder or bedrock, but the flow maintains contact with the substrate. Small cascades may occur in cobble where the bed has a stepped structure due to cobble that has accumulated.



Waterfall

A waterfall has free falling flow over a cliff.

The Hydraulic Biotope Concept and Different River Sciences

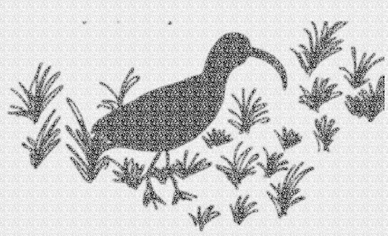
Many of the hydraulic biotope terms given in this section relate to terminology that is used to describe morphological features. Pools, riffles and rapids are examples of this.

In developing the Hydraulic Biotope Concept, it became clear that the time and space scales over which these features develop and endure differs depending on whether they are observed from an ecological or geomorphological perspective. It has been observed that **changes in flow rates can cause changes to hydraulic biotopes by developing them from one type to another.**

This potentially inevitable variation complicates the classification process. For example, if a "pool" hydraulic biotope forms, it can turn into a "run" if water flow and levels through the "pool" are increased. In this case, *morphologically*, the "pool" remains the same; but ecologically, it becomes a "run". The morphological differences are noted in structure: the ecological differences are noted in water flow. That is to say, the morphological pool could have taken 5 -10 years to form and maybe another 5 -10 years to change; whereas the ecological “pool” could be changed almost instantly because it is defined and affected, largely, by immediate flow rates.

Clearly, a river system has much more going on than meets the eye. Often, components that play a vital role in maintaining dynamic equilibrium (biotic and abiotic factors) are not visible to the naked eye, nor are they a part of general knowledge - which is exactly why it is so important to study a river system in its entirety. Holistic study of our fluvial systems can lead to **intelligent development** of water management schemes which we use to tap into their precious resources.

Intelligent development is development that is engineered and managed in a way that imposes minimal environmental impacts, and retains considerable semblance of the natural state of dynamic equilibrium. Ultimately, intelligent development means building dams and IBTs with an awareness of their consequences. This can only happen if one is educated about the environment/river system being targeted for management schemes.



Managing South Africa's Rivers: finding the Reserve & defining a Water Management Scheme

A natural river system that has been influenced by a water management scheme is called a "**regulated river**"; this is because its flow is controlled or "regulated" to serve a purpose. In South Africa, more and more rivers are being regulated as the needs of South Africans increase with the size of the population and with the growth of industries countrywide. In the face of all of this physical and industrial expansion, the following question arises: "What kind of impact will all of these water management schemes have on South Africa's natural river systems, and how can the impacts be managed in a holistic way?"

The affects of river management schemes need not be negative, but preventative measures involve educated decisions regarding the regulation of South Africa's water ways. Being that dams and interbasin transfer schemes have provided the main infrastructure through which South Africa's water resources have been managed, knowing how they influence the river environment is a fairly crucial element to water management.

The Reserve

Managing a river involves more than just deciding where to put an IBT or dam, it also involves **determining the quantity and quality of water needed to maintain a healthy river environment**. This amount must also support the ecosystems that are associated with a river channel, i.e. the riparian zone as well as instream ecosystems. This amount is called the **Ecological Reserve.**

The Ecological Reserve is different for each river, and is determined on a per river basis. Fluvial geomorphologists, along with ecologists, help to determine the quantity and quality of water that must be kept in the river or “reserved” according to the needs of each river in question. The Ecological Reserve is calculated in order that the ecological functioning of a river channel may be maintained in the face of water management schemes.

The role of the geomorphologist in determining the Ecological Reserve is to recommend flows that will keep channel morphology in a condition that is able to provide the diversity and abundance of habitats that are required to keep river plants and animals in good condition. This is important

The RESERVE

South Africa’s National Water Act, No. 36 of 1998 (NWA), recognizes that South Africa’s water belongs to all South Africans. It is up to the government to organize ways that water can be reached and accessed by South Africans in a way that is fair, balanced, and good for the country and its citizens, as well as good for the environment.

In order to help ensure that water is shared fairly between people and the environment, the concept of identifying a Reserve amount of water was developed. This Reserve takes into account the flow and water quality needed to meet the basic human needs of South Africans (e.g. sanitation, health, survival = the **Basic Human Needs Reserve**), but also accounts for the needs of aquatic ecosystems (e.g. river environments = **the Ecological Reserve**). Fluvial geomorphologists are partially responsible for determining the Reserve needs of rivers that are being assessed for management schemes. Determining The Reserve per river is a significant task that must take into account many things such as: water quality, water quantity, and the condition of the river being assessed.

because, as you know, channel morphology determines the types of habitats found in a river and its riparian zone.

Sediment Transport and the Ecological Reserve

Channel morphology is the result of sediment transport processes. A key role of the geomorphologist is to recommend flows that will keep an acceptable balance of sediment erosion and deposition.

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The materials that make up the sediment regime of a river channel occur in many different sizes and weights. Some are very fine silt-like materials that move easily under low flow velocities; others, like large rocks, are much heavier and would take a significantly stronger flow to be moved, like that caused by a flood for example.

Because these sediment materials weigh different amounts and move at different rates, it can be difficult to calculate the exact type of flow a river channel might need to satisfy its Ecological Reserve requirements.

An enormous task indeed!

Albert Einstein's son was a hydraulic engineer who needed to model sediment movement. When asked for advice, his father responded that the problem was far too difficult and that he would rather stick to developing the Theory of Relativity!

Sometimes, in addition to classification charts and time and space scales geomorphologists use more complex mathematical equations to calculate these fairly specific requirements. Geomorphologists are currently working on these types of equations as they attempt to define the Ecological Reserve of individual rivers.

A Sneak Peek at the Order of Operations:
more Q & A with Dr. Mud

Q: So now that fluvial geomorphologists have gathered all of this information, how do they go about calculating the geomorphological component of the "Reserve"?

A. *Understanding the dependency relationship between flow dynamics (i.e. effective and bankfull discharges) and channel morphology is one of the keys to predicting the impact of a water management scheme on a river. There is a particular order in which assessment activities take place:*

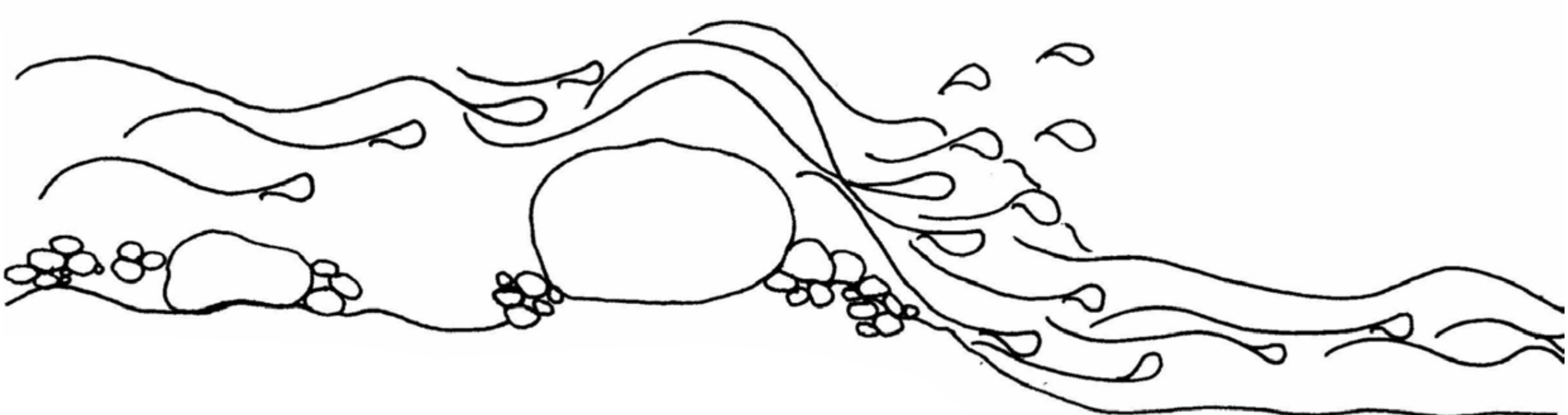
Firstly, the geomorphologist must look at the study reach within the context of the channel network to see how much water and sediment is coming from where. The impact of the dam on changing flow and sediment inputs can then be assessed.

Second, the geomorphologist will use the channel morphology to look for clues as to important discharges. The bankfull discharge is important, but we may also need to know what discharges are needed to flow through side channels or are linked to other morphological features that provide important habitat.

Third, the geomorphologist uses hydraulic equations to calculate the transport capacity for different flow levels. From this we are able to calculate the pre-dam and post-dam effective discharge. We can calculate how the long-term transport capacity will change if we change the frequency of the different flows, and make predictions as to what will happen to the channel size and shape.

None of these methods on their own will give a complete or accurate picture of channel processes. Together these methods contribute to our understanding of channel dynamics and how they are likely to be affected by flow regulation

We then have to assess how these changes are likely to impact on habitat for the stream and riparian biota. The geomorphologist cannot do this on their own, but only through working with the ecologists.



Floods, controlled discharge, geomorphologists, and the Instream Flow Requirement

The Instream Flow Requirement

Under natural conditions, it is rare for a river to experience steady flows, but the natural environment is designed for these fluctuations.

Geomorphologists must determine how man-made water-control schemes can imitate natural fluctuations to a degree that will keep the river environment in a sustainable and healthy condition.

This estimation is called the Instream Flow Requirement, and is different for every river.

The Instream Flow Requirement is defined in part by each river’s rate of effective discharge, and contributes to the assessment of what the Reserve will be for each water management scheme.

Tributary’s and the Instream Flow Requirement

As mentioned, a tributary is a stream or river that feeds a larger river.

If a river has been dammed it will not received sediment from its regular flow and sediment regime, *but* it will continue to receive sediment from its tributaries. What this means in terms of an impoundment is that because the flow regime has been changed it may no longer be able to carry the sediment load that has been added downstream by the tributary. This can cause significant deposition to take place which can significantly affect channel morphology.

Geomorphologists, then, need to consider the sediment regime of the river being dammed as well as the additional sediment materials being added by any tributaries when determining the Ecological Reserve and the Instream Flow Requirement of a river.

Did you know?

There are many biogeoclimatic regions along the entire length of a river channel. A biogeoclimatic region is distinguished depending on climate changes that are influenced by gradient of hillslopes.

The Drakensburg is an example. A river that begins in the Drakensberg experiences completely different climates and geomorphology as it makes its way through the Natal Midlands and then out to sea. Hence, it passes through many biogeoclimatic regions!

Did you also know…

That over 120 types of IBTs exist world wide? They are categorized depending on many things, such as: type of river system, transfer routes, and direction of transfer for example

Water Management Schemes

Well, you've been hearing about them for sixty-some pages now; it's about time water management schemes were revealed. In this final section, you will learn what Dams and Interbasin Transfers are, how they work, and how they influence South Africa's rivers.

Interbasin Transfer Schemes or IBTs

An interbasin transfer or IBT is a water management scheme that organizes the transfer of large amounts of water from an area that has an abundant supply, to an area that has very little. South Africa has turned to IBTs to help bring water to areas of the country that are highly populated but do not have enough water resources to support the number of people living there, and the rate of development (i.e. industry), as well as sustain a healthy river environment

An interbasin transfer takes water from one river and re-routes it to another. The river that gives the water is called the "donor river", and the river that receives water is called the "receiver river". The water is transferred between the rivers and catchments via an enormous transfer pipe which is designed to handle large quantities of flowing water.

The primary impacts of IBTs are to the flow and sediment regimes of the rivers involved, but in particular to the receiving river.

Impact 1: Flow

Being that the point of an IBT is to transfer more water to an area that has less, a river that once had a low flow will suddenly have a much higher flow of water all of the time. Basically, an IBT can add so much water to the receiving channel that it is very full or at bankfull throughout the entire year, instead of only during infrequent high discharge events. Such drastic changes to flow rates and volumes will most certainly cause drastic changes to the morphology and the riparian zone of the receiving river.

Impact 2: Sediment

The second major impact of an IBT is to the sediment regime of the receiving river. Changes to this regime often involve a loss of bank side vegetation.

The loss of cohesive bankside vegetation leaves a river channel susceptible to erosional forces which can widen the channel and cause incision of the river bed. This greatly impacts the morphology of the channel.

It is important to note the role of vegetation in post-IBT recovery processes. As mentioned in *How a River Works: The Basics*, vegetation can work as a channel stabilizer, so the sooner bankside vegetation can recover and adapt to a new flow regime, the better the chances of channel recovery.

Sometimes, new flow rates may not be compatible with the types of vegetation that grow along a channel. This is because the kinds of vegetation that will grow in a river channel, and throughout a riparian zone, will differ depending on rates of flow, sediment materials, and the availability of water. Vegetation and flow and sediment regimes are yet another example of a dependency relationship within a river system.

In some cases, after the implementation of an IBT, new species of plant may have to be established before a bank can be stable again, and this could take a while. In the meantime, erosion and widening of the receiving channel would take place.

In this instance, the job of a geomorphologist would be to recommend the "safest" amount of water that could be added to a receiving river channel but would still maintain its stability and ability to sustain the precious ecosystems associated with its riparian zone.

In South Africa, many dams and IBTs have been built without advice from a geomorphological impact assessment. Some were built many years ago, before assessments were available. Geomorphologists often use these sites in comparison and observation studies which help reveal the long term impacts of water management schemes. Methods of evaluation include comparing a regulated river system with an unregulated river system that mirrors what the characteristics of the regulated river would have been, prior to IBT or dam implementation (i.e. in comparing catchment, river long profile, flow and sediment regimes, as well as vegetative characteristics).

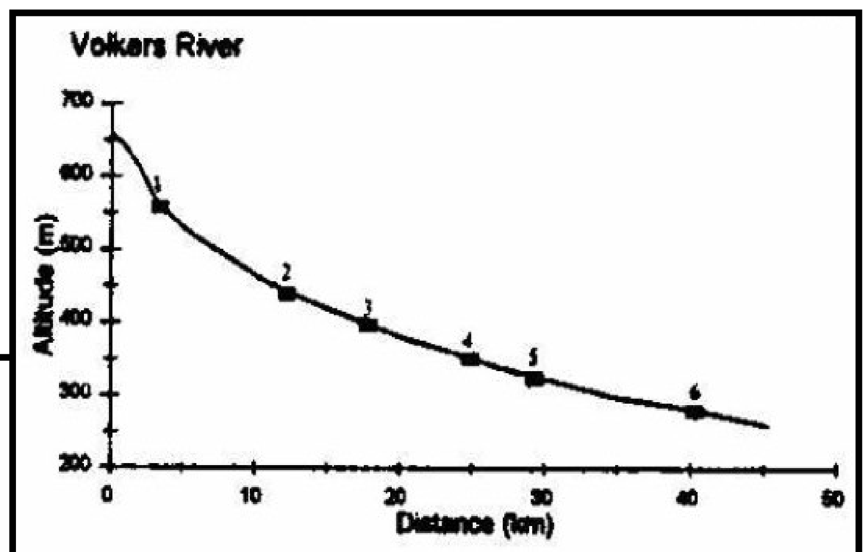
What concerns geomorphologists about interbasin transfers is how the receiving channel will respond to a sudden large increase in water to its flow regime, and what that increase will mean to the morphology of the river channel and its associated ecosystems, especially, the riparian zone.

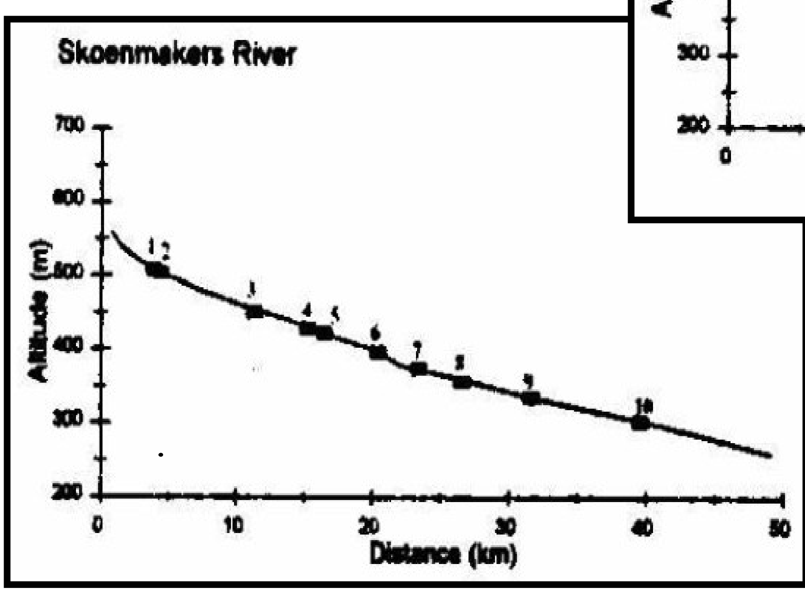
In this way, change and the consequences of change are estimated through observation and comparison with actual changes that have taken place. Through these studies, geomorphologists gain an even better, and more accurate, understanding of the response of river morphology and riparian vegetation to the influence of an IBT or an impoundment.

A Case Study: the Skoenmakers versus the Volkers

Currently, geomorphologists are monitoring the effects of an IBT on the Skoenmakers River by comparing it to the Volkers River. The Volkers River is non-regulated and displays characteristics and a flow regime similar to the Skoenmakers before it became a receiver river. The comparison is being made in order to observe how the Skoenmakers has been affected by the IBT, and to estimate what measures could be taken to rehabilitate the Skoenmakers area. Diagram 14a illustrates the similar river long profiles of the comparison rivers.

Diagram 14a: The River Long Profiles of the Skoenmakers and the Volkers are very similar….



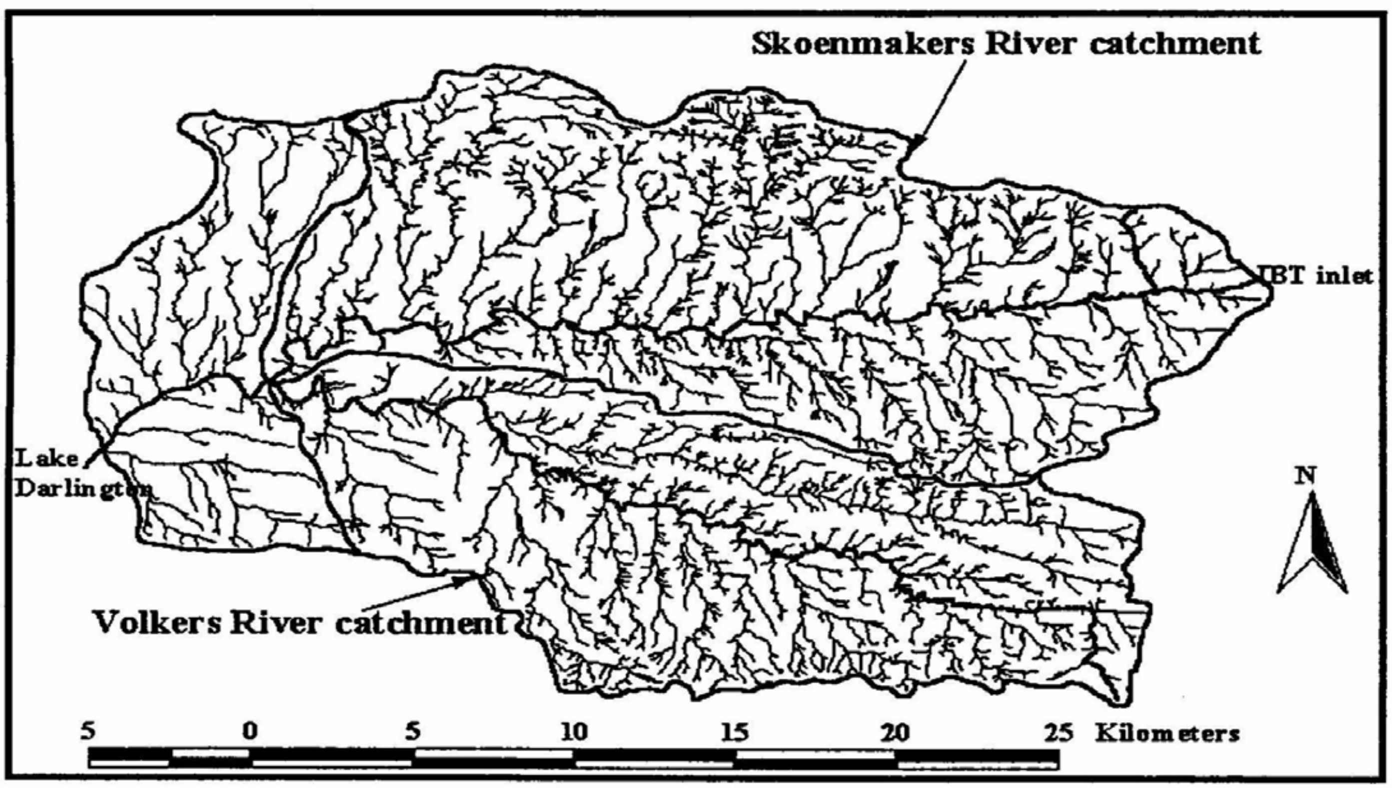


…it is for this reason, in addition to similarities in vegetation, and flow and sediment regime characteristics that the two could be used successfully in comparison studies.

An IBT in Action: the Skoenmakers River

In the case of the Skoenmakers River in the Eastern Cape, an IBT has been built, and the Skoenmakers has become a receiver river that transfers water from the Orange River. The transferred water collects at Lake Darlington and then flows into the Sundays River, where it feeds the city of Port Elizabeth (have a look at figure 14c). This transferred water is also used for irrigation in the Sundays River citrus farms. The amount of water that gets released down the Skoenmakers River depends on the demand for it downstream.

The following diagrams help put the Skoenmakers IBT into geographical and geomorphological perspective.



<u>Diagram 14b:</u> Sub-catchments of the Skoenmakers and Volkers Rivers

The Orange - Fish River - Sundays IBT

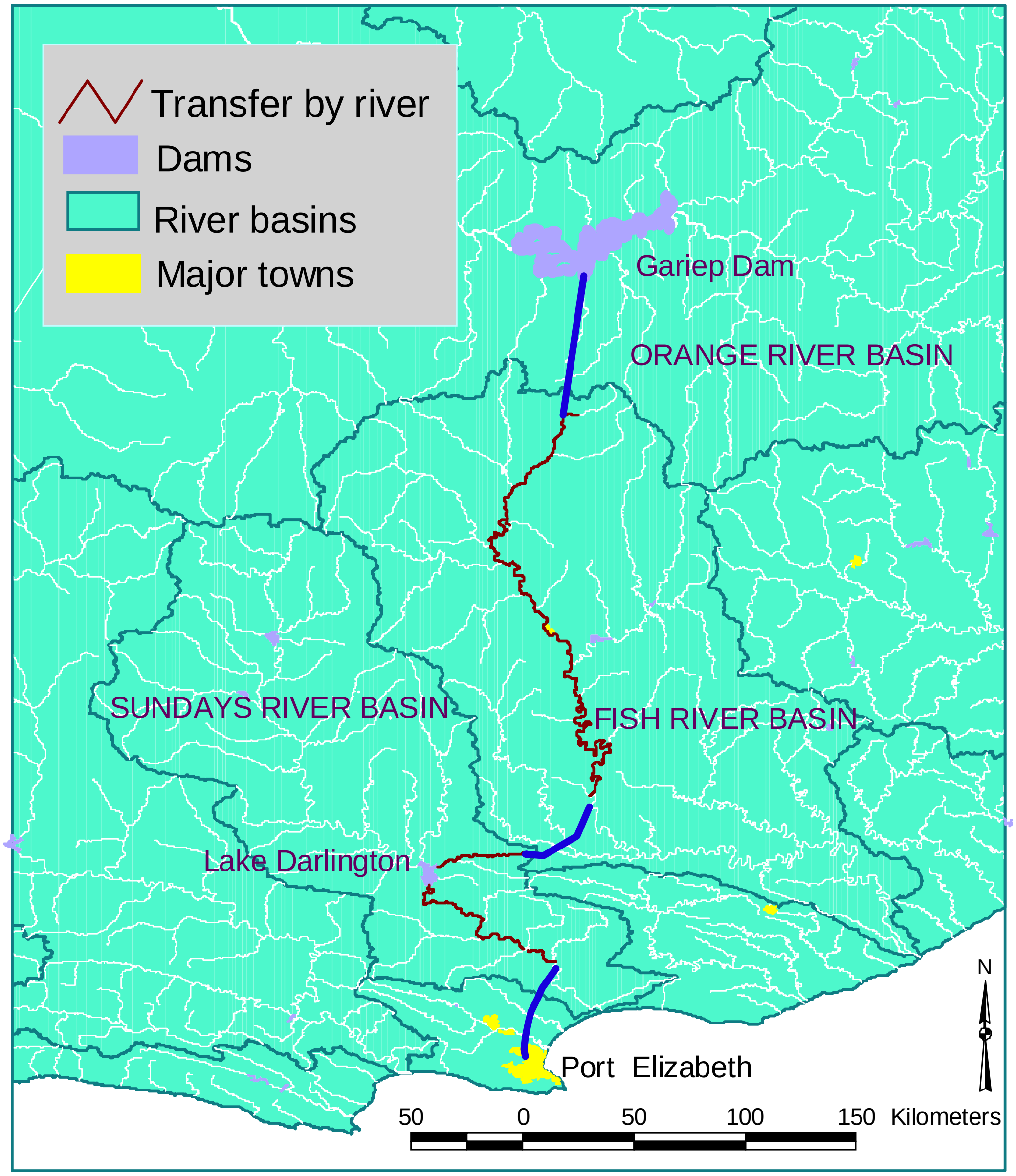


Diagram 14c: The location of the Skoenmakers River IBT within the context of the Orange-Fish-Sundays Rivers Interbasin Transfer.

Before and After the IBT – the Case Study

Before the IBT, it is estimated that the Skoenmakers was an alluvial river channel with quite a steep river long profile. The vegetation of the Skoenmakers River was dominated by a complex mixture of shrubs and grasses that were very dependent on seasonal rainfalls. The interbasin transfer was built to connect with the Skoenmakers River in its upper reaches.

Under natural conditions, the Skoenmakers River was an ephemeral stream (similar to the comparison "natural state" Volkers River), but the transfer of water from the Orange River via the IBT has converted it into a near-perennial river. Just to refresh your memory, an *ephemeral* stream/river is one that does not always flow, perhaps only after rainfall events; and a *perennial* stream/river is one that flows all year round and has a substantial amount of water flowing down it at all times (the reason the Skoenmakers is only a *near*-perennial river is because for two weeks of every year the transfer flow is cut off so that any needed repairs can be made at the IBT site).

It is clear that the IBT has caused dramatic changes to the flow regime of the Skoenmakers River in that, after the IBT was initiated, the river began to flow at a constant high discharge compared to its previous highly limited discharge.

Have a look at the following photographs to see just how different the post-IBT Skoenmakers is compared to before the transfer scheme was built. This is an excellent example of how much an IBT can influence the morphology of a river channel.

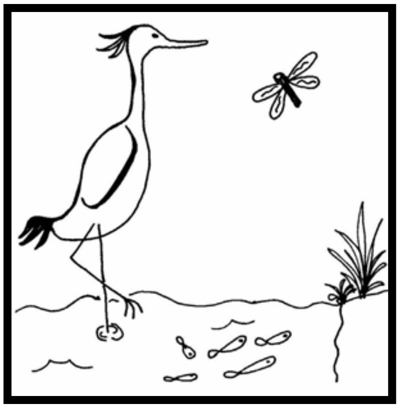
Diagrams 14d-f: These pre-IBT pictures of the Skoenmakers show it was clearly ephemeral river that did not flow year round. The wooded vegetation in the middle reaches of the channel is a testimony to this.

The Skoenmakers after the IBT

Diagrams 14g-i: The post-IBT pictures of the Skoenmakers show how dramatically water levels have been altered in the river channel. From L – R: the Skoenmakers directly below the IBT; the middle reaches of the Skoenmaker; and finally, the lower reaches where deposition is taking place.

Before the IBT, the top of the Skoenmakers channel was narrow and alluvial, a few meters wide, and less than a half a meter deep. The channel gradually increased in size down the length of the river in response to increases in natural flood discharges. Geomorphologists have discerned that the alluvial nature of the river probably extended for its full length.

After the IBT was initiated, the upper sections of the Skoenmakers became deeply incised and widened, bedrock was exposed in the channel bed and the channel straightened as the size of its meander bends increased. This happened as a result of the significant increase in flow to the channel, caused by the IBT. Lower down the channel, sediment eroded from the banks and bed was deposited in the wider channel to form mid-channel bars and other depositional features.

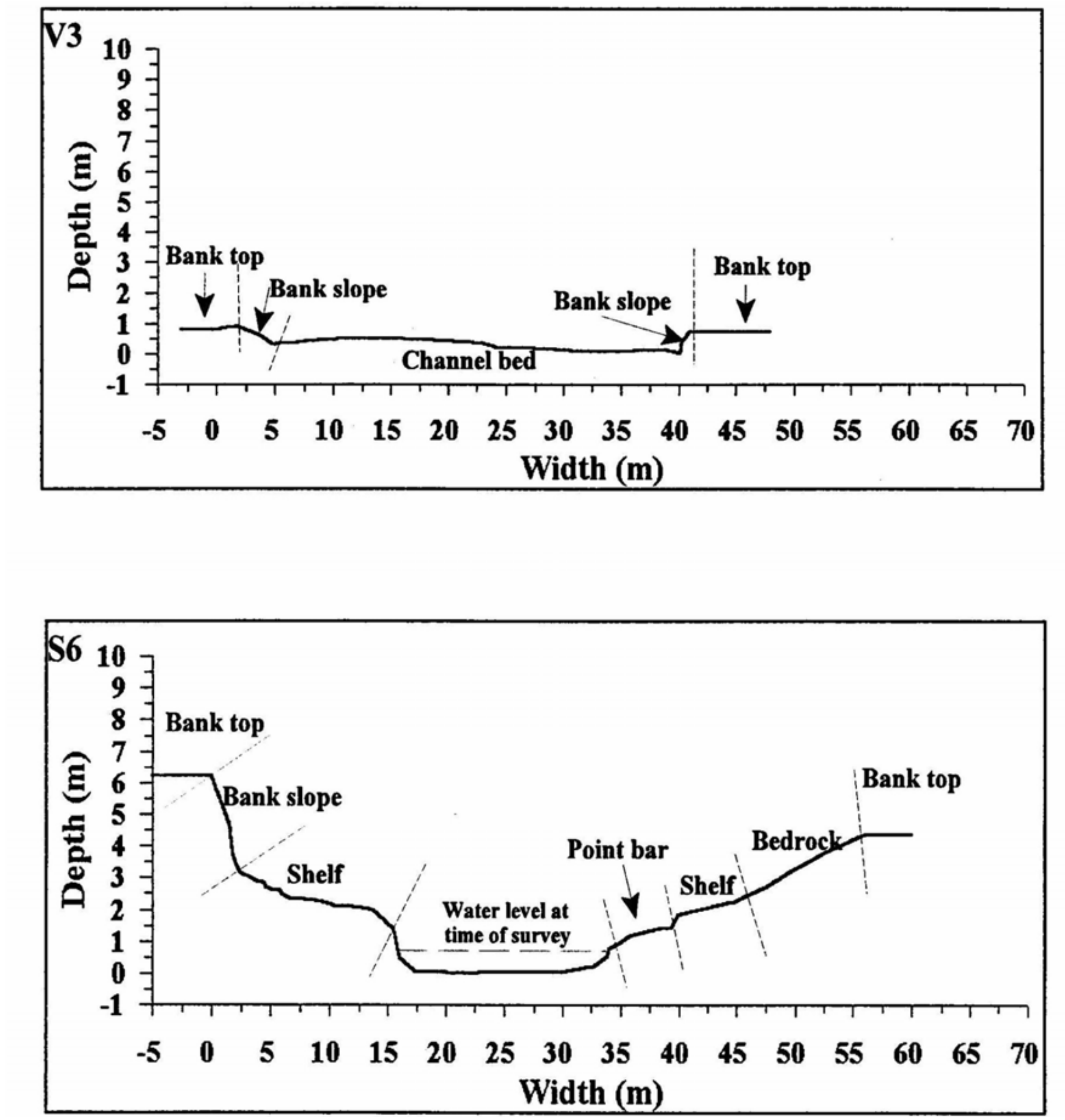


Geomorphologists have found that the Skoenmakers flow regime is now constant, with very little variation in water levels because the river is almost completely fed by the IBT release. This means that the previous riparian vegetation, which was specific to an ephemeral type stream and dependent on variation in water flow levels, was no longer able to survive. As a result, the riparian zone of the Skoenmakers has undergone significant changes. For example, previous upper channel vegetation has disappeared due to active erosion and unstable banks; however, additional vegetation and alternative habitats have developed downstream (i.e. in the lower reaches) as a result of changes in water levels and the availability of water and sediment

Also after the IBT, the banks of the old Skoenmakers were completely eroded and washed away. This caused damage to associated ecosystems and habitats. Measurements and aerial photographs have revealed that the Skoenmakers river channel is changing from a meandering river to one that runs straighter. This is because the new IBT imposed flow regime is making the Skoenmakers River wider and deeper, as more sediment materials are washed downstream.

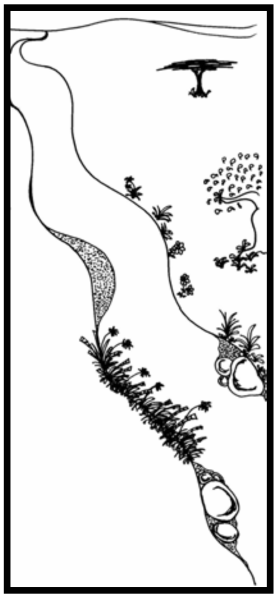
Because the IBT was placed in the upper reaches of the Skoenmakers, the sediment that is washed away by the new high rate of discharge is unable to be replaced at the same rate as it is eroded away. This means that the IBT flows are not only taking the regular sediment materials downstream, but also washing away any mobile river bed materials, thereby incising the channel bed.

As we have learned, looking at the cross section of a river is a great way to see how morphology and flow can influence each other. The following cross sections compare the Skoenmakers River with the Volkers River after the IBT was put in. Note the changes in depth and channel variation.



<u>Diagram 14j</u>: Cross section comparisons of the Volkers (top) and Skoenmakers (bottom) Rivers at their middle reaches illustrate some of the influences that IBT flow have had on the Skoenmakers as a receiving river.

As you know, IBTs are not the only method of water management used in South Africa. The other most common method is the use of Dams.



Dams/Impoundments

Dams are built as a method of water management. In building a dam, water resource managers can control the amount of water that is released down a river channel by impounding it. From there, they can monitor that the impounded water is used in areas where it may be needed most.

As with an interbasin transfer, a dam is an attempt to use available water resources in an efficient way that will support not only the environment, but the development and expansion of human populations. Considering that **less than 1% of all water on earth is fresh** (important to remember when brushing your teeth with the tap running), humans are coming to realize that without water conservation and management, there will not be enough water to support our populations or maintain planet and animal life. This potential lack of resources is of great concern world wide, but especially in countries like South Africa where fresh water resources are often far away from areas where they are needed most.

In order to get water resources to the people and industries (especially and including agriculture) that need them, water is re-routed away from the environment that it supports. As a result, entire river systems, and all life associated with them (human, animal, and aquatic), are compromised. Another method of water management is impoundment, or building dams.

When a dam is built, it impounds river water behind its wall. As the river water collects, it creates an artificial lake; artificial because without human interference (by building the dam), the lake would never form.

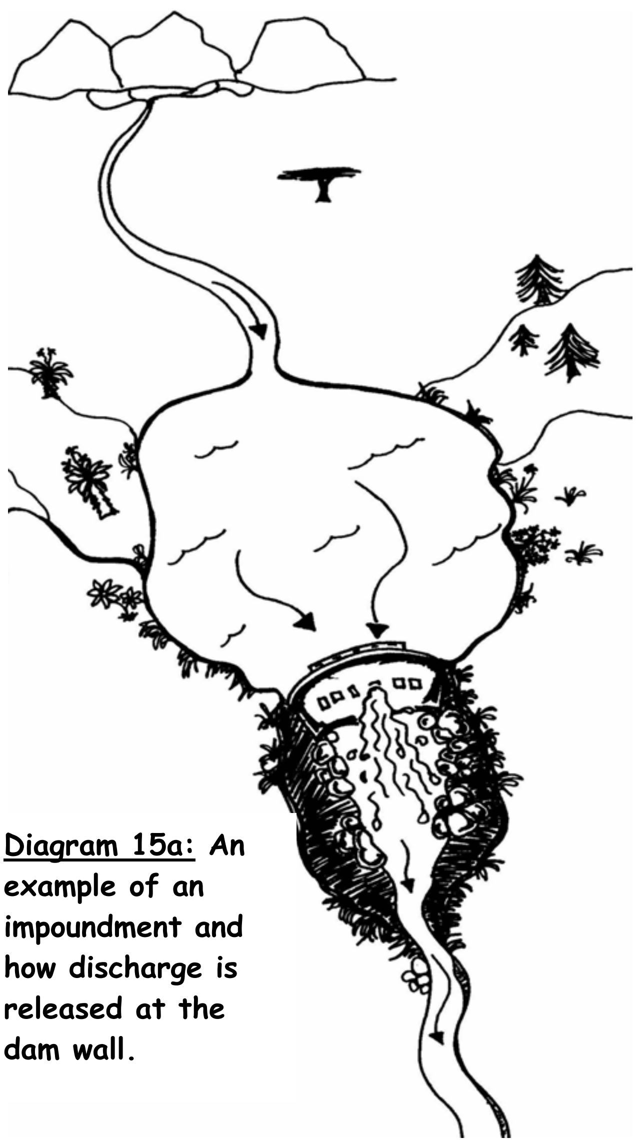


Diagram 15a: An example of an impoundment and how discharge is released at the dam wall.

The release of the impounded water is controlled by water managers who monitor how much water is being collected, and how much water is needed downstream. They then decide how much water will be released and control the rate and quantity of release at the site of the dam wall. The effects of this water collection and controlled release are what concern geomorphologists and ecologists alike – especially in regards to the river downstream of the dam. This often has its water supply cut off (resulting in an imbalanced dynamic equilibrium), and its sediment regime altered dramatically by the presence of the dam.

The River Downstream

When a dam is built, the part of the river below or downstream from the dam changes dramatically because it no longer receives its regular flow and sediment regime; however, the river above the dam doesn't change much as it carries on flowing like it always did. Except now, instead of sediment and water carrying on downstream as it normally would, it eventually builds up and slowly begins to fill the reservoir or impoundment. The main problem resulting from this, as you may have guessed, is the continual deposition of sediment materials within the impoundment. Normally, a river's flow regime would carry on moving sediment materials down to the lower reaches of the channel and out to sea, but the insertion of a dam wall prevents this from happening.

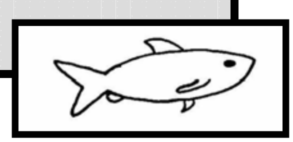
While a dam can control the release of water, it cannot so easily rid itself of sediment that is continuously being deposited into it. Eventually, a dam can become useless as it is continually filled by sediment so that its capacity to store water is lost. This may take many years to happen, or it may only take a few – it depends on the river's flow and sediment regime.

Impoundment/Dam

► These terms are often used interchangeably. Literally, dam means*, a structure that has been built to impound water*, and an impoundment, refers to the water that has been "impounded" for controlled use.

Reservoir

► A reservoir is the artificial lake that is created when an impoundment is put on a river. Phobane Lake is the reservoir created by the Goedetrouw Dam that has been built on the uMhlatuze River.



You may have guessed by now, that how a river channel is influenced by a dam can depend upon where the dam is placed (i.e. at what point along the channel), and how it is operated (i.e. how much water is released down the channel). You may also have guessed why fluvial geomorphologists are able to give advice on those exact things. That's right, it's because they are river scientists and they understand flow and sediment regimes, and how river systems respond to change.

> Dams trap 90-100% of fine material sediments, and 100% of coarser material sediments. (McGregor, 2000)

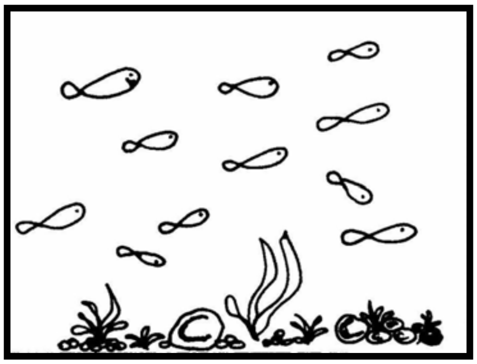
Dams: Impacting Rivers

Dams, like IBTs, influence river systems and geomorphological processes by impacting flow and sediment regimes. Dams reduce the natural variability of a flow regime and thereby weaken the role of natural events (like floods) in a river environment. Dams also trap sediment, thereby preventing it from moving through a river system and leaving the channel more susceptible to erosion and incision.

Explaining the Impacts

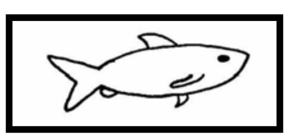
An important engineering function of a dam is to control floods and protect areas downstream of the dam from flooding events. Although floods are often perceived as a hazard and a "wasted" resource (because of all of the water that flows down the river and out to sea without being "used" for anything) we have already learned otherwise: that floods play an important role in maintaining the structure and function of a river channel - especially by transporting and shifting sediment.

Ecological processes are also dependent upon floods. For example, floods scour gravels by flushing out fine sediment materials, thereby providing a fresh habitat for spawning fish to reproduce. Floods also provide ecological cues for life-cycle stages of vegetation and aquatic organisms. For example, some water-born species only reproduce when certain natural flow events occur; if these events are stopped or changed, those species cannot carry on with their lifecycle as they normally would – this could become a problem if those species are the food for other animals or humans.



Floods also cover flood plains and replenish riparian zones. With this action, they may trigger life cycle processes for certain types of vegetation; as we have learned, this is important because river banks without cohesive vegetation or with unhealthy riparian zones are very susceptible to erosion and are unable to provide healthy habitat for river environment species to propagate and flourish.

Being that change effects change, the side effects of building a dam are felt not just by the river banks and the bottom of the river channel, but by those who depend upon the river as part of their livelihood. Let's go back to the uMhlatuze River to learn a bit more about it and to find out how the Goedetrouw Dam caused the changes that it did, not just to the river channel, but to the lives of those who utilize the river on a regular basis.



The uMhlatuze: a Dam in Action

The uMhlatuze River in Kwa-Zulu Natal runs through many farms, with each farmer in need of generous amounts of water for irrigation. The uMhlatuze also flows through many rural towns before it reaches the sea, and is a main source of water for the city of Empangeni as well as the industrial areas of the quickly expanding Richards Bay area. Water supply has become a concern in these regions as the industrial area of Richards bay is expected to double in size in the next 20 years.

It was decided that a dam would be the best way to help ensure an adequate and consistent supply of water for the urban, industrial, and rural areas that depend upon the uMhlatuze. In 1979 the Goedetrouw Dam was built on the uMhlatuze, and Phobane Lake was created

The uMhlatuze River before and after the Dam

Before the Goedetrow Dam was built the uMhlatuze would have been a wide, sandy, alluvial river; after the dam was built, the character of the river downstream of the impoundment changed. Now, the uMhlatuze that runs through the Nkwaleni Valley is more of a mixed channel, with very patchy areas of sandy sediment and a much higher presence of rocks, boulders and cobblestones. Of course, the rocks, boulders and cobblestones were always there, they were just previously covered by large amounts of sandy sediment. Also, the channel has become narrower, with dense vegetation proliferating along the edges of the banks, even overhanging the main channel (remember Leroy du Preez complaining about not being able to tube because of encroaching vegetation). Why have these changes occurred, and is all of this change a bad thing?

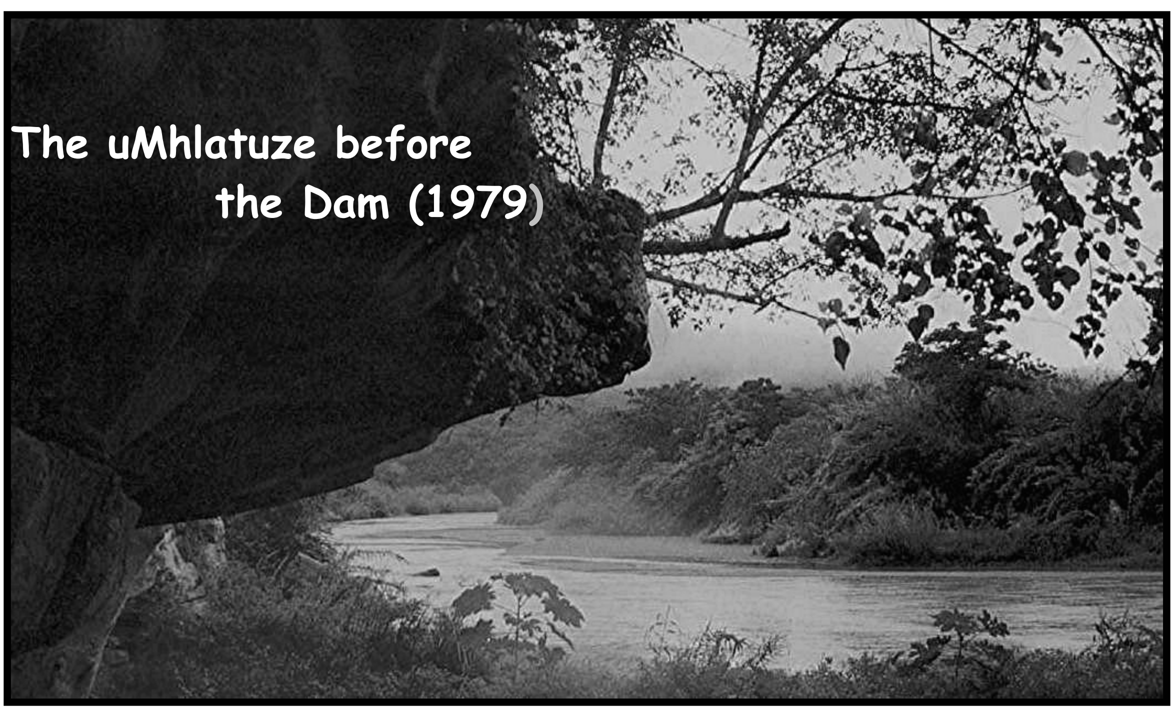
The Goedetrow Dam has had two immediate impacts on geomorphological impacts below the dam. The most obvious effect of the dam is that it stores large volumes of water and reduces the amount of flow in the channel. Twenty five kilometers below the dam the flow through the channel in an average year has been reduced by 65 %. 35 kilometers further downstream, in the next segment (below the Mfuli tributary), the reduction in flow is less, but it is still only 50 % of the natural flows. Likewise, flood volumes have been reduced by similar amounts. This means that the capacity to transport sediment has been reduced. Twenty five kilometers below the dam the sediment transport capacity has been reduced by 75 % and a further 35 kilometers it has been reduced by 50 %. This means that any sediment entering the channel is likely to build up in the form of channel bars, either causing the channel to become narrower, or forming islands in the middle of the channel.

The storage of water and sediment in the Goedetrow Dam reduces the capacity of floods to transport sediment and erode the channel, but also reduces the availability of sediment in the channel.

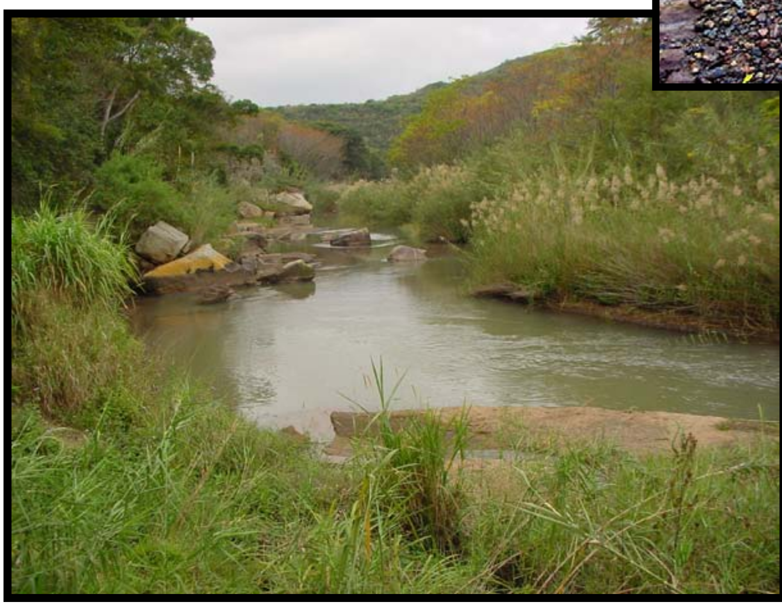
Although the capacity of the flow to transport sediment has decreased, the amount of sediment to be transported has also decreased. This is especially so immediately below the dam wall. All sediment of sand size and larger will be trapped by the dam, and even much of the silt. This means that water leaving the dam is “sediment hungry” and easily picks up any available sand or gravel. The larger cobbles and boulders are left behind, leaving a stable, armoured river bed. We can now see why the uMhlatuze below the dam has changed from a sand bed river to a coarse bedded river dominated by boulders. Moving down stream, away from the dam wall, sediment starts to enter the channel from eroded banks or from tributaries, so the amount of sand increases. Once past the Mfuli tributary, the uMhlatuze returns to a sand bed river, but now it is smaller than it would have been before the dam was built.

Another important process that happens below a dam is related to the vegetation. Removal of fine sediment in the upper reaches of the post-dam channel removes suitable habitat for vegetation, but wherever vegetation does find a suitable area for rooting, the reduction of large floods means that it can become more firmly established, and better able to withstand a large flood when it does manage to get through the dam. Once vegetation becomes established, the chance of sediment becoming deposited also becomes greater. Thus loss of flooding leads to more vegetation, leads to more deposition, and leads to smaller deeper channels. This is one of the processes that has been happening in the uMhlatuze.

Diagram 15b: Note: this is the same site as the bottom photograph of those taken after the Dam was built – site 15e. Can you see the changes?



The uMhlatuze after the Goedetrouw Dam was built (2003)



<u>Diagrams 15c-e</u>: Compare this photo (L) with the pre-Dam picture to contextualize some of the changes that the Nkwaleni farmers are talking about.

Habitat has also changed along the uMhlatuze. As we have seen, the uMhlatuze has become a narrower channel with much less sediment, and a fairly constant regulated flow regime. The loss of sand and exposure of cobble and boulders has changed habitat from a more uniform sand bed channel with glides and runs to a coarse bedded channel with a higher diversity of hydraulic habitats. Is all of this change a good thing, or a bad thing? It depends on who or what you are. The river is certainly removed from its natural state, but it may be able to support a higher diversity of organisms. The crocs don't seem to mind because since the dam was put in, there have been several sightings, where there were none for many years. Some farmers might complain about the morphological changes, while others will be pleased with the changes in water supply. Have a look at how a change in water supply effected Black Fly populations along the Fish River. Keep in mind that these changes can occur whether flow is influenced by an IBT or by a dam.

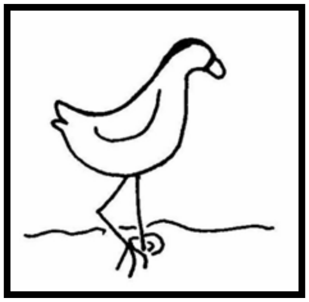
Dependency relationships between ecological processes and Dynamic Equilibrium

An example: Black fly proliferation and the Fish River IBT

As we have said, there are certain types of plants and insects that rely upon the variation in temperatures and water levels that changing seasons bring to a river system. Often, when a water management scheme is implemented, those factors that were once variable become constant. For example, water levels that used to fluctuate may become constantly high or constantly low. Such a change inevitably affects the animals, insects and plants that depended on the previous variations. It is just as important to be aware of the ecological consequences of the implementation of a water management scheme, as it is to be aware of the geomorphological consequences. The black fly proliferation that took place following the Fish River ITB is a good example.

Black flies need a particular type of hydraulic biotope condition to reproduce. Natural weather conditions only permitted the black fly to reproduce during certain times of the year; populations would die off in the winter when the river dried up. However, the IBT changed those conditions and provided summer flow conditions all year round. The black fly was then provided with conditions that were conducive to breeding all year round. This proliferation of black fly populations had very adverse effects on the local cattle populations who were getting infections and suffering from open sores as a result of the fly's rasping tongue, which would continuously aggravate any wounds.

This example illustrates very well how dynamic equilibrium works in a river system, and illuminates the ecological/geomorphological connection.



It is important to point out that change is not always about bad and good; rather, the concern with change has to do with *sustainability*. Can the changes, natural or anthropologically imposed, maintain a sustainable environment? If flows in the uMhlatuze are no longer variable, how long will it take for vegetation to completely encroach parts of the channel? How many organisms were eliminated when their habitats changed with a suddenly constant flow of water, devoid of finer sediment materials, and what does that mean downstream? These issues bring us to another important concept that has been developed by ecologists to help guide river management. It is called, the Present Ecological State.

The Present Ecological State (PES) of a river is an assessment of the degree to which the present river ecosystem has been modified from its natural condition, and the extent to which the health of the ecosystem may be lowered by loss of suitable habitats. The Present Ecological State is normally assessed by comparing the river to what geomorphologists think it would have been like under natural conditions, otherwise known as the Reference Condition. The PES gives a measure of change from the natural condition. This does not mean that a low PES is necessarily bad.

The next step in the management decision-making process is to decide on an Ecological Management Class (ECM). This is the class that the team of ecologists (including the geomorphologist) recommend should be maintained under managed conditions. It recognises that the physical structure of a river may change as a result of development processes, and that river associated ecosystems also change.

In selecting an ECM ecologists try to balance the different needs of the ecosystem with those of the people using the river. In the case of the uMhlatuze, the Ecological Management Class would recognise that the structure of the river cannot be changed back to what it was before the dam, so that in setting flows for the Ecological Reserve geomorphologists would need to provide for the new ecosystem that has become established there, rather than trying to restore the natural or reference condition.

A Re-Cap

So, what have we learned about fluvial geomorphology?

We have learned that as a river science fluvial geomorphology can play a vital role in helping explain the way a river environment works and how it is affected by change.

We have learned about dependency relationships, i.e. that the components of a river environment shape the morphology of the channel and vice versa; and we saw how helpful time and space scales are in indicating rates of change over time and space.

We have also learned that catchment variables such as climate, topography, vegetation cover and soil type determine the flow and sediment regimes of a river; and have been shown how, at the reach scale, things like bed and bank sediment characteristics and riparian vegetation determine channel stability and form (morphology).

We learned how a holistic approach to studying a river environment can provide a detailed and more accurate assessment of the effects of water management schemes (ecological and morphological).

Ultimately, we have been led by the science of fluvial geomorphology on a journey through the river system, and have seen how important this science is to sustainable development of water management schemes. We also learned why sustainable development is important by discovering the role that rivers and water play in our every day lives

A Conclusion

As you have well gathered, there is much more to rivers and fresh water than meets the eye. So much change, so much life, so important to ensuring the survival of not only our natural environment, but the survival of human kind.

We need water to ensure our future and the future of the river environments that we depend upon in so many direct and indirect ways. Therefore, it cannot be surprising that scientists like geomorphologists are being asked for their professional opinion as to *how to best move ahead* with managing rivers as main water resources.

It becomes clear, the more we learn about rivers, river environments and our dependence upon them, how interconnected the aspects of the planet are and how taking care of them is important (e.g. littering pollutes your immediate environment).

One of the great things about geomorphology is that it does not work like many traditional sciences, breaking down the parts and treating them as individual separate entities independent of each other. Geomorphology, rather, considers the river channel as a *whole* – a sum of many equally important parts that influence each other in ways crucial to the survival of the environment, habitats, animals and ecosystems within and around it. In this way, geomorphology, especially when combined with other sciences that study different components of a river system, is a science of the future; a science working to conserve the present in order to sustain the future of *our changing rivers*.

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Diagrams Bibliography

All drawings and diagrams by Natasha Freeman except for the following:

Diagram 6a: From - Rowntree, K.M., & Wadeson, R.A. WRC Report No. 497/1/99 *A Hierarchical Geomorphological Model for the Classification of Selected South African Rivers*. The Water Research Commission. Johannesburg, South Africa. p.63 [Controls on channel pattern formation, after Kellerhals and Church (1989)].

Diagram 9b: From – Rowntree, K.M., & Wadeson, R.A. WRC Report No. 497/1/99 *A Hierarchical Geomorphological Model for the Classification of Selected South African Rivers*. The Water Research Commission. Johannesburg, South Africa. p. 32 [Time – Space relationships in, 1) alluvial systems and b) bedrock systems. *a) Time-Space relationships in alluvial systems; Time-Space relationships in bedrock systems*].

Diagram 10b: From – Rowntree, K.M., & Wadeson, R.A. WRC Report No. 497/1/99 *A Hierarchical Geomorphological Model for the Classification of Selected South African Rivers*. The Water Research Commission. Johannesburg, South Africa. p.10 [A hierarchy of small catchments nested within a larger one].

Diagram 10d: From - Dollar, EJS & Rowntree, KM. WRC Report No. 849/2/03 *Geomorphological Research for the Conservation and Management of Southern African Rivers. Volume 2: Managing Flow Variability: The Geomorphological Response*. The Water Research Commission. Johannesburg, South Africa. July 2003. p.67 [Long profile of the uMhlatuze].

Diagram 10e: Courtesy of Kate Rowntree

Pictures 12b-e: Courtesy of Kate Rowntree

Diagram 14a: From - Rowntree, K.M., & du Plessis, A.J.E. WRC Report No. 849/1/03 *Geomorphological Research for the Conservation and Management of Southern African Rivers. Volume 1: Geomorphological Impacts of River Regulation*. The Water Research Commission. Johannesburg, South Africa. July 2003. p.73 [figure 5.3: Long Profiles of the Volkers and Skoenmakers rivers].

Diagram 14b: From - Rowntree, K.M., & du Plessis, A.J.E. WRC Report No. 849/1/03 *Geomorphological Research for the Conservation and Management of Southern African Rivers. Volume 1: Geomorphological Impacts of River Regulation*. The Water Research Commission. Johannesburg, South Africa. July 2003. p.72 [Figure 5.2.: Subcatchments for the Skoenmakers and Volkers Rivers].

Diagram 14c: Courtesy of Kate Rowntree

Pictures 14d-i: Courtesy of Kate Rowntree

Diagram 14j: From - Rowntree, K.M., & du Plessis, A.J.E. WRC Report No. 849/1/03 *Geomorphological Research for the Conservation and Management of Southern African Rivers. Volume 1: Geomorphological Impacts of River Regulation*. The Water Research Commission. Johannesburg, South Africa. July 2003. p.92 [Comparison of two cross-sectional profiles for the middle reaches of the Volkers (V3) and Skoenmakers (S6) approximately 25km below the point of inflow of the IBT].

Pictures 15b-d: Courtesy of Jonathan Freeman

Picture 15e: Courtesy of Gareth Chittenden