HOW TO...

manage Water Quality and Water Quantity together

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WHO ARE THESE HANDBOOKS FOR?

The user-friendly series of "How to…." handbooks are aimed at staff and stakeholders in catchment management forums (CMFs), catchment management agencies (CMAs) and municipalities. The handbooks are not all written at exactly the same level of "user-friendliness", it depends on the topic, and target users.

The list below shows which groups are likely to find the handbooks most useful:

TITLE	#	CMF	CMA	MUNICIPALITIES
How to think and act in ways that make Adaptive IWRM practically possible	1		√	√
How to think about water for people and people for water: Some, for all, forever	2	√	√	√
How to establish and run a Catchment Management Forum	3	√	√	
How to manage Water Quality and Water Quantity together	4		√	√
How to engage with the challenges facing Water and Sanitation Services (WSS) in small municipalities	5			√
How to run a Green Drop campaign in a Catchment Management Forum	6	√	√	√
How to engage with coal mines through a Catchment Management Forum	7	√	√	√
How to use Strategic Adaptive Management (SAM) and the Adaptive Planning Process (APP) to build a shared catchment future	8	√	√	√
How to understand Environmental Water Quality in Water Resources Management	9	√	√	√

NOTE: Words marked with an * in these handbooks appear in the glossary at the end of each handbook.

Definition: **Adaptive IWRM:**
Using adaptive, systemic, processes and an understanding of complex social-ecological systems **to coordinate conservation, manage and develop water, land and related resources across sectors within a given river basin, in order to maximise the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems.**

A definition based on the Global Water Partnership 2000 definition of IWRM (Agarwal et al., 2000), with specific Adaptive IWRM additions (italics).

Background

All over the world water resources are under pressure due to over-use and pollution, and finding ways to meet the need for water is becoming increasingly difficult. Natural variation in rainfall also contributes to making planning and management of flow and water quality, and especially these together, complex and difficult.

People have realised that it is important to consider many factors when managing water – they call this **Integrated** Water Resource Management (IWRM). Integrating many factors is in line with the ideas that all the "How to" handbooks are based on. Please do read the foundation handbook: "*How to think and act in ways that make Adaptive IWRM practically possible".*

In this handbook we consider how to integrate flow and water quality.
Although some writers think taking account of all the many factors is too difficult, others – including the authors of this handbook – believe it is essential to try if we want to find the balance between use and protection. IWRM also recognises that it is vital to involve stakeholders in decision-making if protection of our water resources is going to be successful.

The South African constitution paves the way for IWRM by supporting environmentally sound, sustainable economic and social development policies. The National Water Act and National Water Resources Strategy2 both give details of how IWRM should work. But currently, management of ecological sustainability has failed notably – and, in South Africa, there is a steady decline of surface water quality.

At present …

- water **quantity** is carefully planned and managed using rainfall, flow, water storage, water treatment information and technology, and licensing of water abstraction;
- water **quality** is managed by monitoring many water quality variables in the environment and in waste streams, monitoring how living organisms respond to pollutants, and by issuing waste discharge licences.
  (See the handbook "*Environmental Water Quality in Water Resources Management*" for the basics of water quality).

Waste is diluted, transported and processed by water. BUT, the licensing of abstraction – which controls how much water there is to dilute, transport, and process wastes – is not linked to the licensing of waste discharge.

This handbook provides a guide to how you can use flow and quantity information TOGETHER to check what actual instream flow AND quality is likely to be. This can be done reasonably simply with existing information and technology.

Knowing how to combine flow and quantity information can be used in two important ways.

1) You might need to be able to do this integration yourself:
    - you can learn HOW to do this, and how to use the results in water resource management, planning, and control.
2) You may not need or want to know how to do this yourself, but:
    - you might have a role in water management, or be a concerned citizen. It is not necessary to know HOW to link water quantity and quality, but you do need to know that it is possible, to lobby for this to be DONE. You can possibly also to learn how to interpret the results.

This handbook is acts as a starting point for both positions 1) and 2) above.

The handbook explains some of the fundamental basics of water quality and quantity, and the relationship between them. Once these two basic water factors are managed together more often in more places, it will be a huge integration breakthrough in caring for our most precious resource.

Building an integrated water quality management process (IWQMP) for efficient water use.

As water becomes scarcer, it is increasingly important to manage it as efficiently as possible. Rain is excellent quality water – and the runoff from the land after rainfall becomes the natural water quality of an area. As humans use water, the quality of the water changes, often to the point where the natural ecosystems and other users are threatened. Historically people used waterways to dilute waste; this was the most common way of dealing with water quality impacts – and still is. This is not an efficient use of water.

But, how do we know integrating water quality and quantity will be a breakthrough in water use efficiency, through managing water quality and quantity TOGETHER? Because we have done it.

Lead author, Hugo Retief, applied the newly developed water quality-quantity model Water Quality Systems Assessment Model (WQSAM) (Slaughter et al., 2011b) in the Crocodile River (West).

The Crocodile River is typical of South African Rivers in that multiple-use of the systems has resulted in deteriorating water quality. Polluters include: mining (metals), agriculture (sugar and fruit), industry (pulp and paper) and domestic effluent from wastewater treatment works (WWTW).

We used the Adaptive IWRM approach that is the basis of all the *"How to…."* handbook series. Through quarterly meetings over three years, we engaged with water users and water resource managers in the catchment, and met with the Crocodile River Forum. Two post-graduate researchers, Retief (2015) and Sahula (2015), worked to achieve three goals:

1) to apply WQSAM,
2) to use WQSAM results together with a social science study of people involved in the sugar industry in order to understand how WQSAM results could best be made available to users, and
3) to investigate water quality in relation to a downstream water user, in this case the sugar industry.

We worked in close co-operation with the Inkomati-Usuthu Catchment Management Agency (IUCMA). They provided the students with offices and logistical support and included them in their daily water quality management tasks to ensure the research results would find their way into practice. This is "learning by doing", which is explained in the "*How to think and act in ways that make Adaptive IWRM practically possible"*. In this way, an integrated water quality management process for the Crocodile River (Palmer and Munnik, in press) was built co-operatively. This process is currently being used in the Olifants River (AWARD www.award.org.za/iwrm/).

Also described in the *"How to think and act in ways that make Adaptive IWRM practically possible"* handbook, we learned to understand catchments as complex social-ecological systems, and learned that implementing plans is uncertain and difficult.

But … success! When the water quality-quantity model was applied and the software for implementation installed at the IUCMA.

The engagement with water user stakeholders had highlighted that what the water users MOST wanted to know was **water quality data, integrated with flow data**. This was needed to support users in polluting less and using water for dilution more efficiently.

In the Crocodile River Catchment this was achieved by running the WQSAM model and reporting it on the IUCMA website. The system is ready to go as soon systems to connect WQSAM with flow reporting are implemented. We hope the final step will be taken soon.

This final step is a challenge as the hydrological model supporting WQSAM needs to be updated regularly. Using this system regularly in all catchment management institutions will require more thinking about institutional and technical capacity.

The water quality-quantity technical method in the context of Adaptive IWRM powerfully influenced the development of South Africa's new Integrated Water Quality Management Policy and Strategy (DWS, 2017), which is based firmly on these concepts:

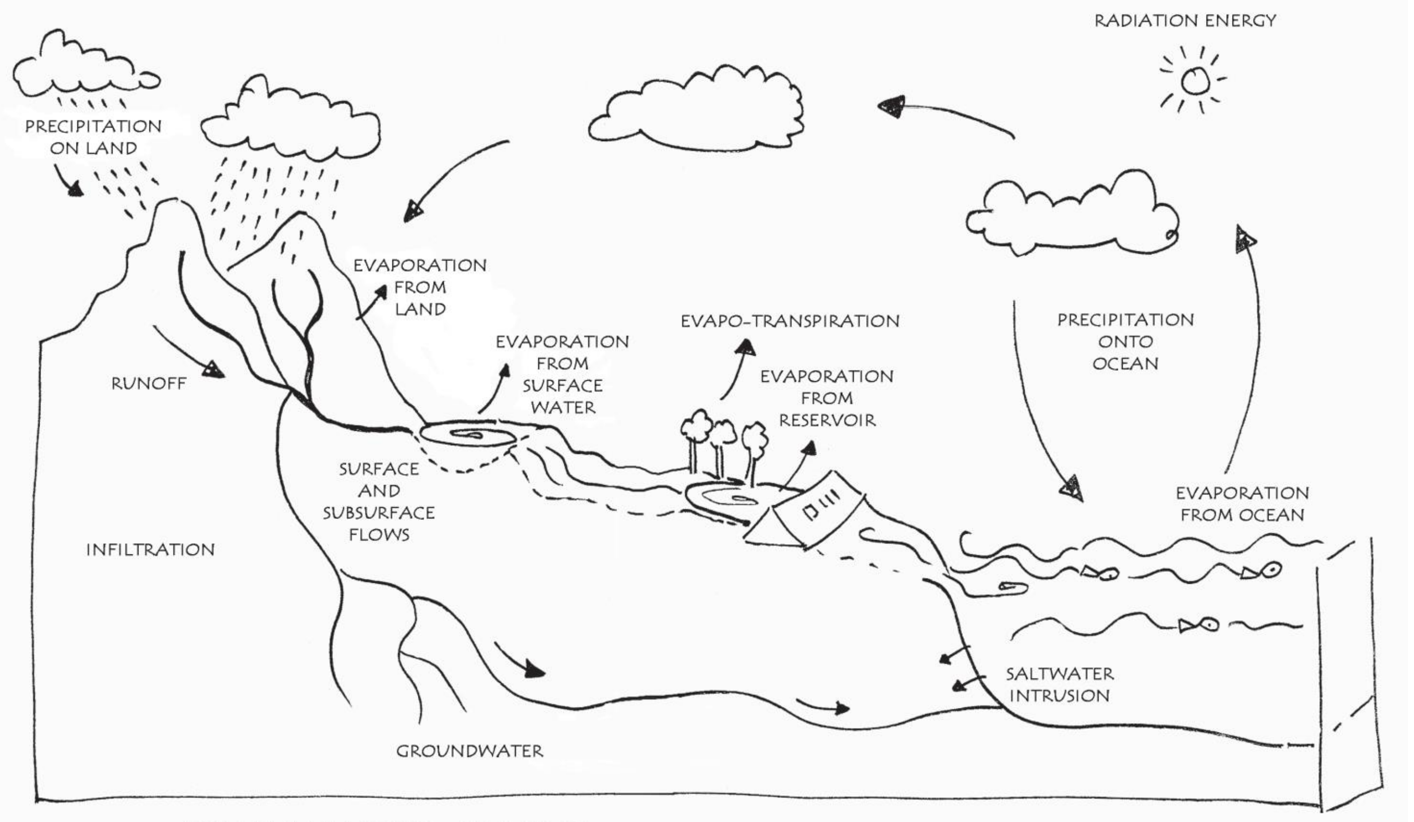
- accepting that catchments are complex social-ecological systems,
- the absolute necessity of integration process, and
- the central need to integrate water quantity and quality.

This handbook is critically important to everyone who works in water resource management, and especially in Catchment Management Agencies (CMAs). It takes the reader from the very basics of quality and flow to a detailed step-by-step method for water quality/quantity integration. It does not introduce the reader to the WQSAM model – for that you need to go to the original literature. (Slaughter et al., in the reference list). Accessible information about the effects of water quality variables on aquatic (water) ecosystems can be found in Dallas and Day (2004).

WATER QUANTITY

What is Water Quantity?

A catchment is a land area on which rain falls. Water quantity in a catchment is based on the water cycle. Water evaporates from land, vegetation, and water surfaces, and is also actively pumped out by plants into the air, where it condenses, and rain falls. The rain flows into rivers, lakes, wetlands and estuaries, and is stored in dams and in underground spaces as groundwater. So, water quantity refers to the volume of water within all these ecological and built infra-structures. Water quantity can be measured and the information can be used in calculations and models to find answers to a variety of questions. Important questions include: How do we make sure there is enough water for people in the homes? Enough water to drive industry and agriculture? How do we make sure that enough water stays in ecosystems to make sure they function well, too?



THE WATER CYCLE

Why is the quantity and quality of water in an aquatic ecosystem (lakes, rivers, wetlands, estuaries or in the groundwater) important?

Aquatic, or water ecosystems PROVIDE SERVICES to people. They:

- supply water: carrying and holding all the freshwater on the earth;
- dilute wastes, transport wastes and process some wastes – especially sewage;
- supply natural products such as reeds, medicinal plants, and fish;
- provide habitats for other living creatures. All living things together make up our biodiversity – and together offer these services;
- assist with flood control – especially wetlands;
- provide people with places for recreation;
- provide places of spiritual value, and places that satisfy the human need for beauty.

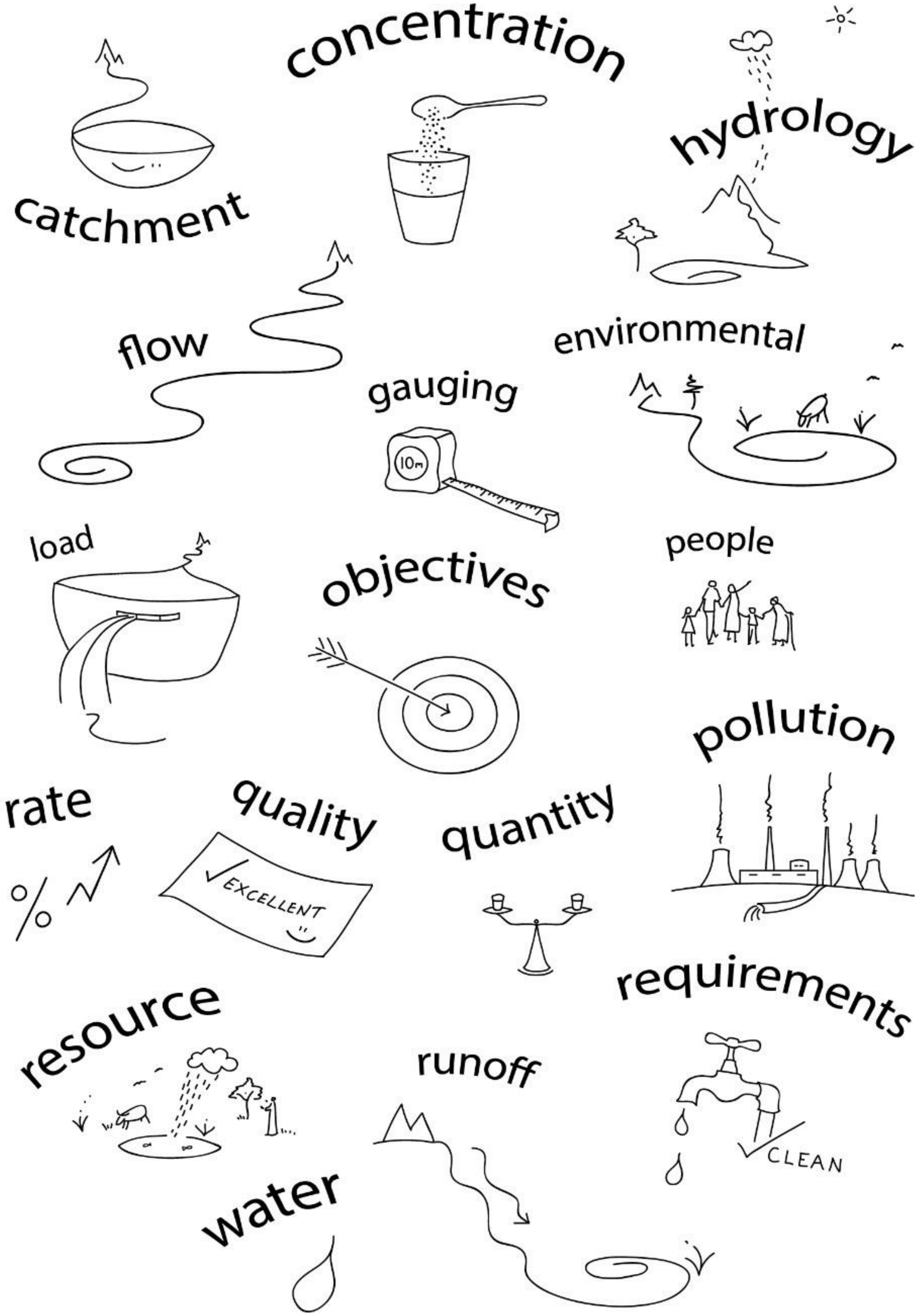
As we USE the services of supply (by abstraction) and waste control (by waste discharge) we reduce the ecosystem's ability to offer the other services.

Therefore, we need to balance water resource USE with water resource PROTECTION

See the Handbook No: 2: How to think about water for people and people for water: Some, for all, forever

Some important water QUANTITY (flow) terminology and concepts

The following words are some of the most commonly used water quantity terms used in water resources management. It is important to become familiar with these terms as you will often find them in meetings/reports/papers, and this handbook. Please refer back to them when needed.



Abstraction: This is the process of taking water out of the ecosystem either permanently or temporarily. For example, 'abstraction' may be used to describe lawful and unlawful water use within the catchment: for example, if a farmer has exceeded his licence limit for specified lawful abstraction, and extracts more water than he is allowed, that extra abstraction is unlawful.

Baseflow: The water that moves at a deep level through soil and rocks towards a stream channel. Baseflows are exceptionally important; they contribute most of the water we can see in streams. In **drought years,** baseflows keep our major **perennial** rivers flowing. **See 'Interflow and groundwater flow'.**

Catchment area: (Often used interchangeably with other terms like **watershed and drainage basin**.) This is an area of land with a rim of higher land where water flows down to a stream in the valley. The water that can be seen is **surface runoff.**

Discharge: (Also referred to as river flow or **streamflow**) Water moving past a particular point over a time period. The term 'discharge' is also used to describe the practice of disposing/returning effluent back into a system. Discharge is the flow of water into a stream – from upstream, or from another inflow. **See 'How do we measure flow?'** below.

Drought water year: A **water year** is the amount of water flowing past a particular point over a 12-month period from 1 October to 30 September. A drought water year is a year when flows are below the long-term average. This causes a hydrological imbalance – a water shortage. Drought years are caused by prolonged hot, dry conditions combined with little **precipitation** (mainly rain). The worst droughts that have been experienced in South Africa have been associated with El Niño Southern Oscillation (commonly called ENSO) events – a warm ocean condition.

Drainage basin: This is the same as a catchment, but it is a term usually used for a larger area, e.g. the whole area where all the surface water flows into the ocean. For example, the Limpopo River Basin is comprised of multiple catchments, e.g. Olifants and Letaba Rivers that flow as tributaries into the Limpopo River, which then drains into the ocean.

Environmental water requirement: (also termed an **'**instream flow requirement'). The National Water Act of 1998 requires that an amount of water, of a particular quality be left in water ecosystems such as rivers, wetlands and ground water. The amount and quality of water is called the ecological **reserve**, and is calculated for each section of a river. This water makes sure the river functions well as an ecosystem. Less water and poorer water quality has a bad effect on the river. If you are interested in the ecological reserve, read the handbooks "*How to think about water for people and people for water: Some, for all, forever"* and "*Environmental Water Quality in Water Resource Management".*

A short summary of the Reserve: for basic human needs and the environment (ecological Reserve)

South Africa's National Water Act (NWA) emphasises that all aspects of water on earth are connected, and we have to manage water resources within this connected cycle. The Act recognises that water belongs to the whole nation and is administered by the government for the good of the people. The Act protects the **rights** of

1) all people to have water for their basic needs (drinking and personal hygiene – 25 litres per person per day); **and**

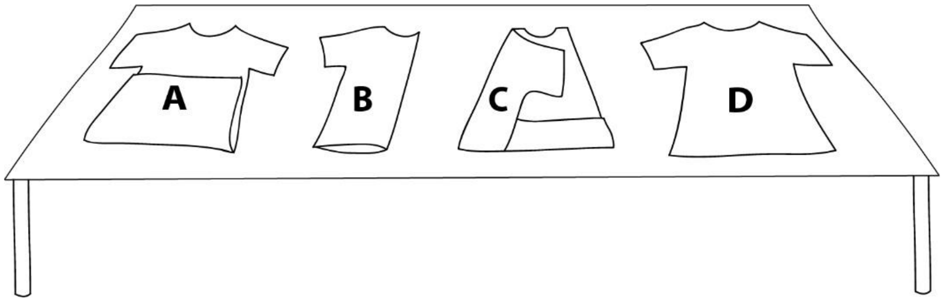
2) water to ensure ecosystem function.

Water for the Reserve is a right guaranteed by law. All other water use is allocated by licence.

Ephemeral: Describes rivers, tributaries and streams, etc. that do not flow continuously throughout a **water year (**the 12 months 1 October-30 September)**,** or indeed every year**.** (See **'Perennial'** below)

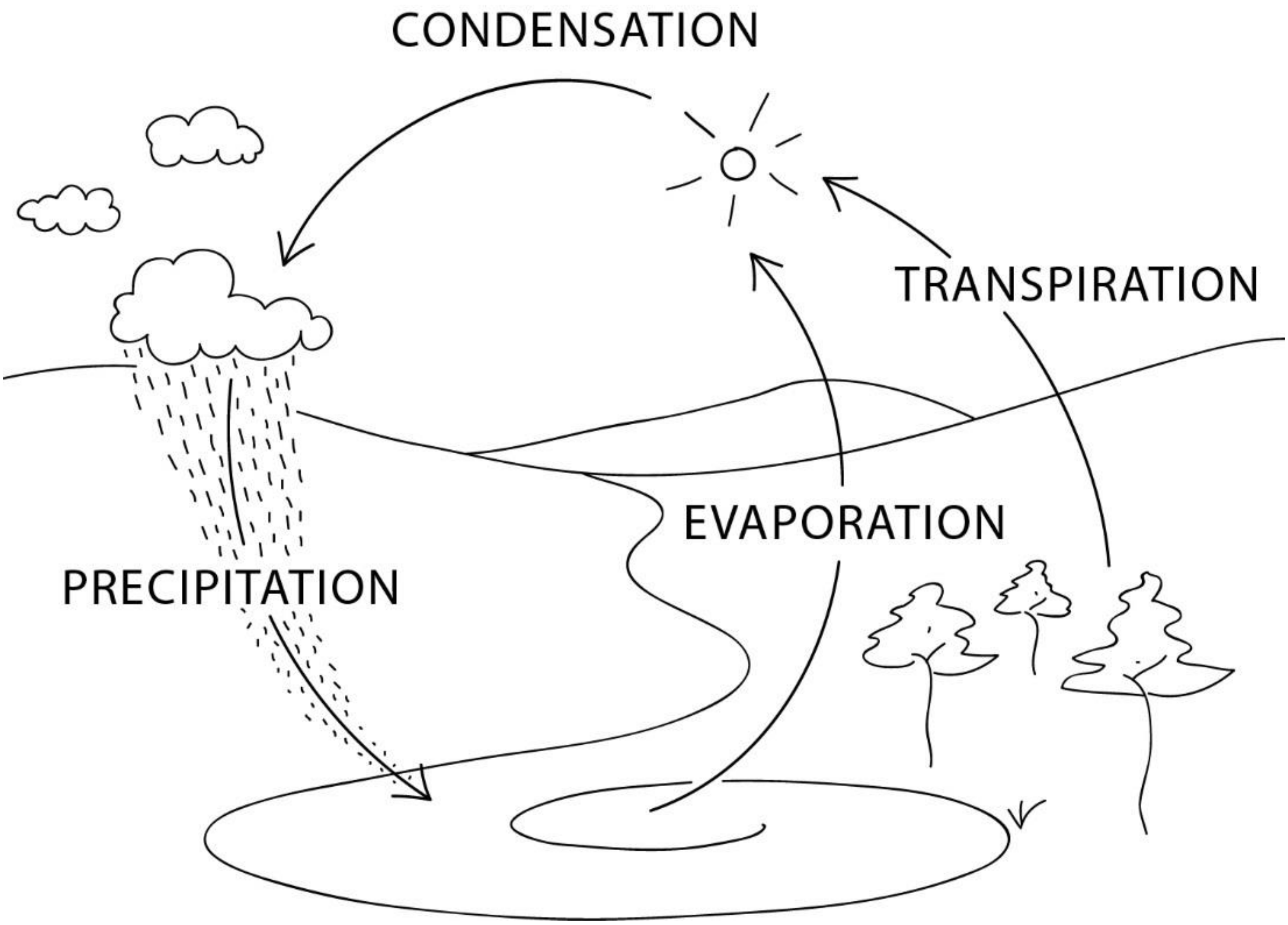
Erosion: A process in which surface water mobilises sediments. The main causes of erosion created by people (anthropogenic-driven practices) are activities like poor land-use management (e.g. over-grazing), open-cast mining, etc.

Evaporation: Water can be found in three states: solid (ice), liquid (water) or a gas (water vapour). Evaporation is the process where water becomes water vapour, and is naturally driven by the energy (heat) from the sun. Water evaporates more quickly from large, warm water bodies – for example, shallow dams with large surface areas. Water loss from a catchment as a result of evaporation can be significant.



Question: If all four of the above t-shirts are wet and placed outside in the sun, which t-shirt will dry the quickest, and why?
Answer: D will dry most quickly because it has the biggest surface area for evaporation; the others are folded in ways that reduce the surface area.)

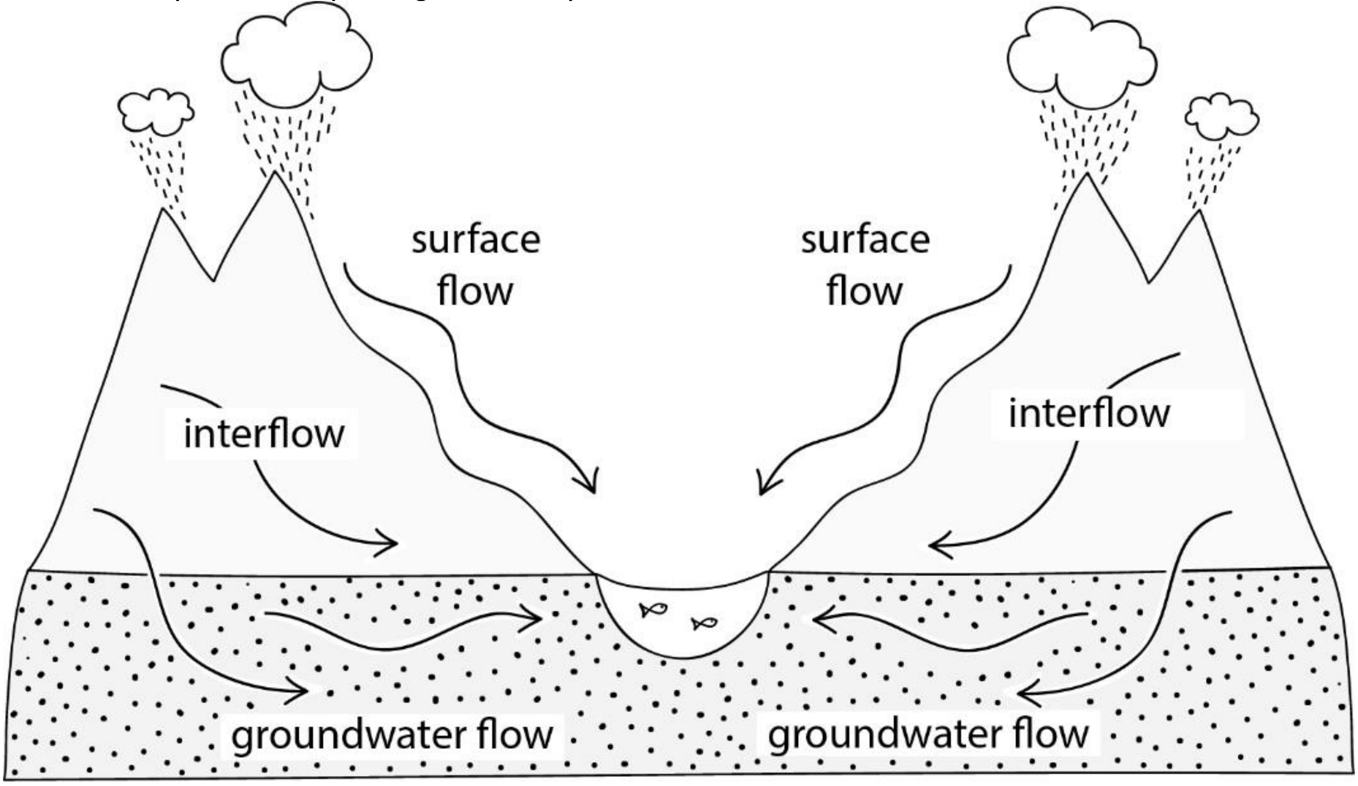
Evapotranspiration: Water loss due to simultaneous **evaporation** and **transpiration**.



Flow duration curve: A graph that is a way of demonstrating and understanding water flow. Start with information about the rate of water flowing past a site, for example, every day at the same time, over a period of time (for example, 10 years). [Detailed instructions on how to construct and interpret flow duration curves are given at the end of this section.]

Flood: An unusually heavy and/or prolonged rainfall event that results in an area of land that is normally dry, being inundated (covered) with water that usually comes from a nearby stream, river, wetland, dam or coastal water.

Groundwater Flow: The flow that comes from below the interflow (sub-surface) zone, commonly associated with aquifers* consisting of underground rock, clay and sand that can store, intercept and/or transport water (see figure below).



Headwaters: The streams that are the source of a river. These are extremely important to everyone who lives in the catchment. They are often called 'water factories' as they are usually in higher rainfall areas. They are also often the only 'nearly natural' streams that can give us a picture of the natural ecology of a river.

Interbasin transfer: The practice of exporting water from one catchment to another. In South Africa, we use pipes, pumps and dams. In time, donor catchments like the Orange River basin, may start to experience shortages.

Interflow: The sub-surface water flow through permeable soils above the **groundwater** zone (see diagram above).

Lag: The delay, or time taken, for water to flow from one point to another. This concept is important in water resource management. For example, if we are using dam releases to maintain the flow at a point downstream to ensure that the environmental water requirement is met, or for irrigation, we need to calculate the time it will take for the water to travel to the point downstream. When managing flows, a pro-active response is needed, not a re-active response, and therefore, accounting for lags in the system is one of the key steps towards achieving good water management.

Lentic and lotic systems: Lentic refers to any water body that is stationary (e.g. a dam is a lentic waterbody as the water is not moving). 'Lotic' is used to describe any water bodies that are mobile (e.g. a river).

'Normal' water year: A 12-month period (1 October-30 September) of water flows, where the flows are within the long-term average.

Perennial: Any water body that flows (**lotic**) throughout a water year. South Africa's perennial rivers are under immense stress as more and more of these are becoming **ephemeral** rivers, as happened when the Olifants River in Kruger National Park stopped flowing for a significant period of time in 2005.

Precipitation: Rain is one kind of precipitation – other kinds are mist, snow, hail and sleet, which all transfer water in the air to water on the land.

Reservoir: Constructed infrastructure designed to store water; may also be called a dam. Dams/reservoirs are NOT lakes. Lakes are naturally formed, whereas dams and reservoirs are manmade, though dams have a similar ecology to lakes. There are very few lakes in South Africa. One example is Lake Sibaya in KwaZulu-Natal.

Riparian zone: The area of a river or stream where vegetation grows on the banks. Riparian zones are extremely important and provide many ecosystem services (e.g. protection from flooding, reducing erosion, providing habitat, etc.). If we do not maintain environmental flow requirements for rivers, we run the risk of damaging the ecological health of the riparian zone, and reduce its ability to provide these key ecosystem services.

Runoff: The water that flows towards a river or stream, either along the surface of the catchment, or underground. This flow is comprised of **baseflow, interflow** and **surface flow**.

Source water contributions to streamflow: The flow in a stream can come from surface flow, interflow or groundwater. It is possible to use specialised techniques to measure each of these. Substrate-driven hydrological processes* were poorly understood in the past, but advances in geochemical and isotope tracer studies* have made it possible to assess the **source contributions** to streamflow (whether from ground flow, interflow or surface flow).

Streamflow, discharge or **river flow:** All of the water that flows in a stream or river. The most commonly used unit of measurement for flow in South Africa is cubic metres per second (cumec). (See section on 'How is water quantity measured, flow rates')

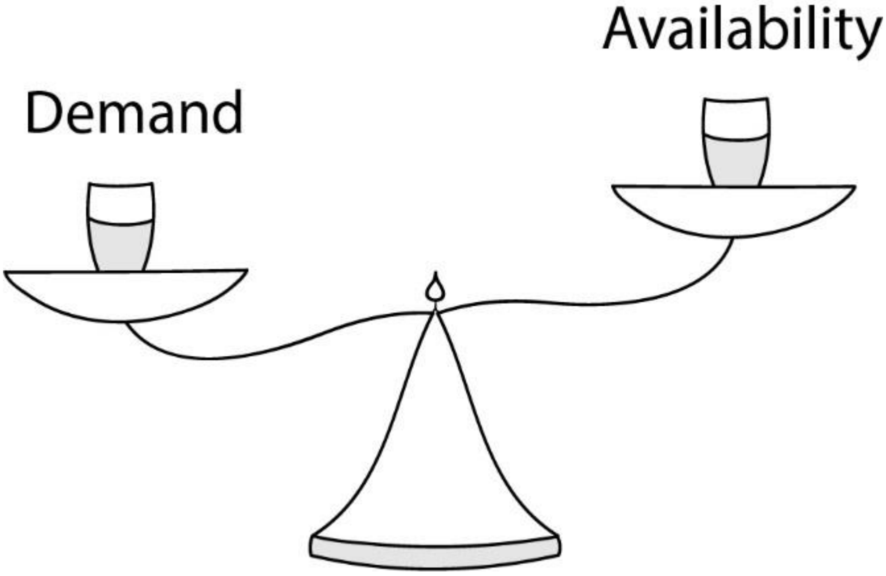
Surface runoff: The water that travels on the land surface towards a river. Surface runoff plays a big role in water quality and will be discussed later in more detail (see Transient events).

Time interval: The period of time, for example 10 years, during which the rate of water flowing past a specific point is measured, every day at the same time.

Transpiration/evapotranspiration: The process where water moves from vegetation to the atmosphere.

Yield: This refers to the amount of water that is produced as a result of rainfall, which flows into a part of the catchment (land surface), or the entire catchment, over a specific period of time (e.g. per year). Yield can be applied at multiple scales – for larger or smaller land surface areas. The yield does not take into account human abstractions (demand), therefore, we can imagine it as the volume of water that flows out of a catchment (or part of a catchment) through surface channels or sub-surface channels (e.g. interflow or groundwater).

Water balance: This is the water we have available in the catchment compared to that which is needed by people for their daily activities (e.g. water for industry, agriculture, and domestic use). It is the balance between supply (availability) and demand.



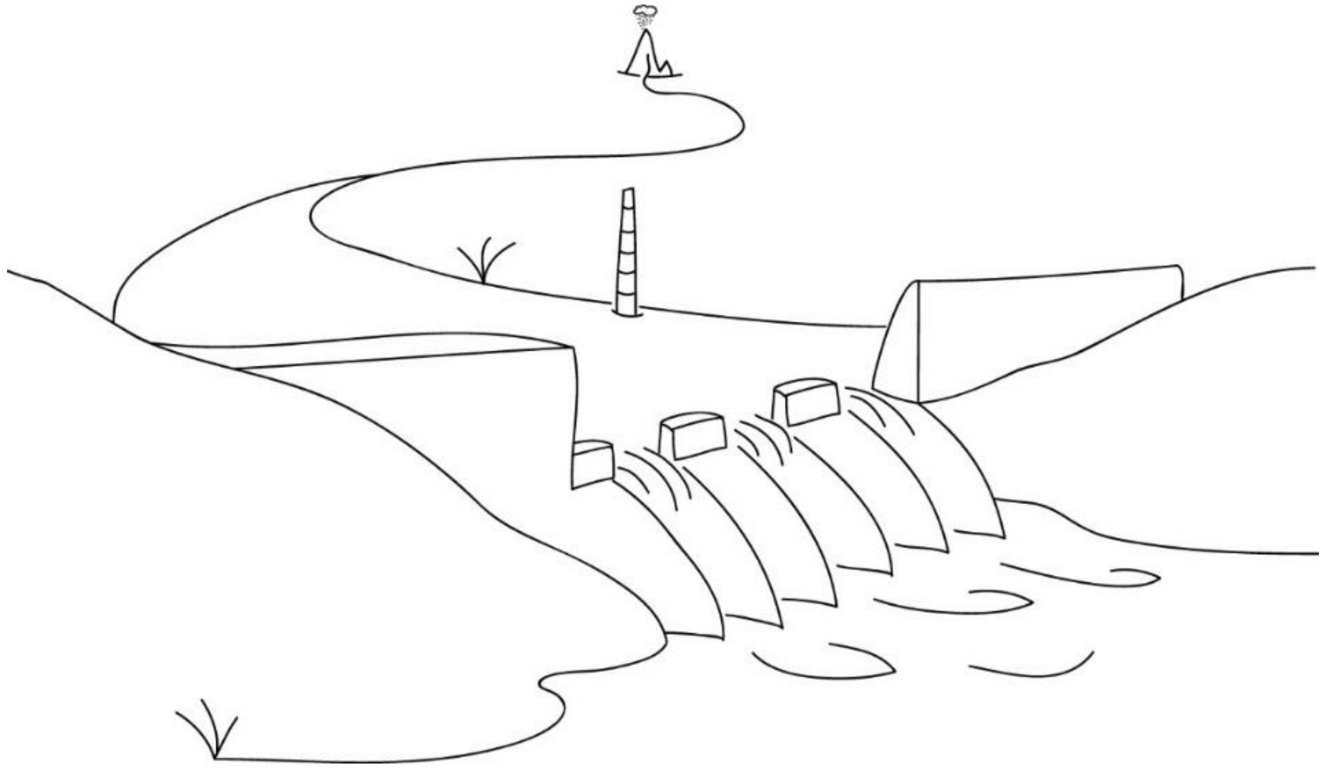
Water year: A calendar year is from 1 January to 31 December; however, a **water year** is from 1 October to 30 September. The selection of the chosen start and end date differ, depending on where you are in the world; for example, in the northern hemisphere the water year is related to snowfall, but in the southern hemisphere, e.g. in South Africa, the water year is related to the start of the wet period (rainy season).

Weir: A manmade barrier spanning the width of a river. Weirs play an important role in measuring how much water passes per second at the specific point in the catchment where the weir is located. A weir is a well-designed structure that channels water through a defined geometry (shape), and by using the area of this shape and the depth of the water, we can determine the discharge (flow). If there is no weir, we have to use a cross-section of the river, with depths at intervals to determine the flow. See the picture below of a weir located on the Olifants River which shows how the weir spans the full width of the river.
Weirs play a vital role in:

1. measuring dam release volumes;
2. determining the quantity (**load**) of pollutants flowing downstream;
3. early warning systems for floods, for example, and
4. monitoring environmental water requirement flows.

Historically, data could not be communicated directly from weirs, and data collection relied on people going out to the weirs to check the flows. This is still the situation in some places today. However, rapid advances in telecommunications and monitoring technology have made it possible to gather information remotely by using probes which measure weir levels known at particular, or stage, heights. These are then linked to data loggers which store the measurements in a memory, and send the data to a computer. If we know what the **stage height*** was at a specific time, we can determine the flow volume at that time. This data is then accessible offsite, for example, on your computer or cell phone. The information can be widely available and accessible to all those involved in decision-making. For example, if the environmental water requirement is not being met**,** dam releases, water restrictions, investigations of unlawful water use or abstraction licence reviews could be implemented.

At connected gauging weirs (weirs at which flow is measured), flow data can be sent every minute if wanted, however, the most commonly used time period that is used is 6 hours. This data is known as unverified flow data, and can be accessed at the Department of Water Affairs and Sanitation website:
http://www.dws.gov.za/Hydrology/Unverified/UnverifiedDataFlowInfo.aspx.



How do we measure water quantity?

Flow in a river does not stay the same. It can increase or decrease, depending on rainfall or a release of water from a dam, and the water constantly moves downstream, driven by gravity. Therefore, there is no simple way to determine exactly how much water (volume) is available in the catchment at any given time. **Flow rates** are calculated as a way of determining the volume of water moving through the river at a given time, at a specific point.

How to develop and interpret flow duration curves: A flow duration curve is a graph that helps us demonstrate and understand water flow. Start with information about the rate of water flowing past a site, for example, every day at the same time, over a period of time (for example, 10 years).

The rate of flow in a river is often measured in cubic metres per second (cumec). A cubic metre per second (or cumec) is 1000 litres per second flowing past a point.

You can calculate what percentage of time the flow rate is equal to, or greater than 0, 1, 2, 3, 4, etc. cumecs. This ‘equal to or greater than’ flow information, is called ***flow exceedance*** data. From this information, you can then draw a graph plotting flow rate in cumecs against percentage of time a flow is equalled or exceeded. An example is shown on the graph below.

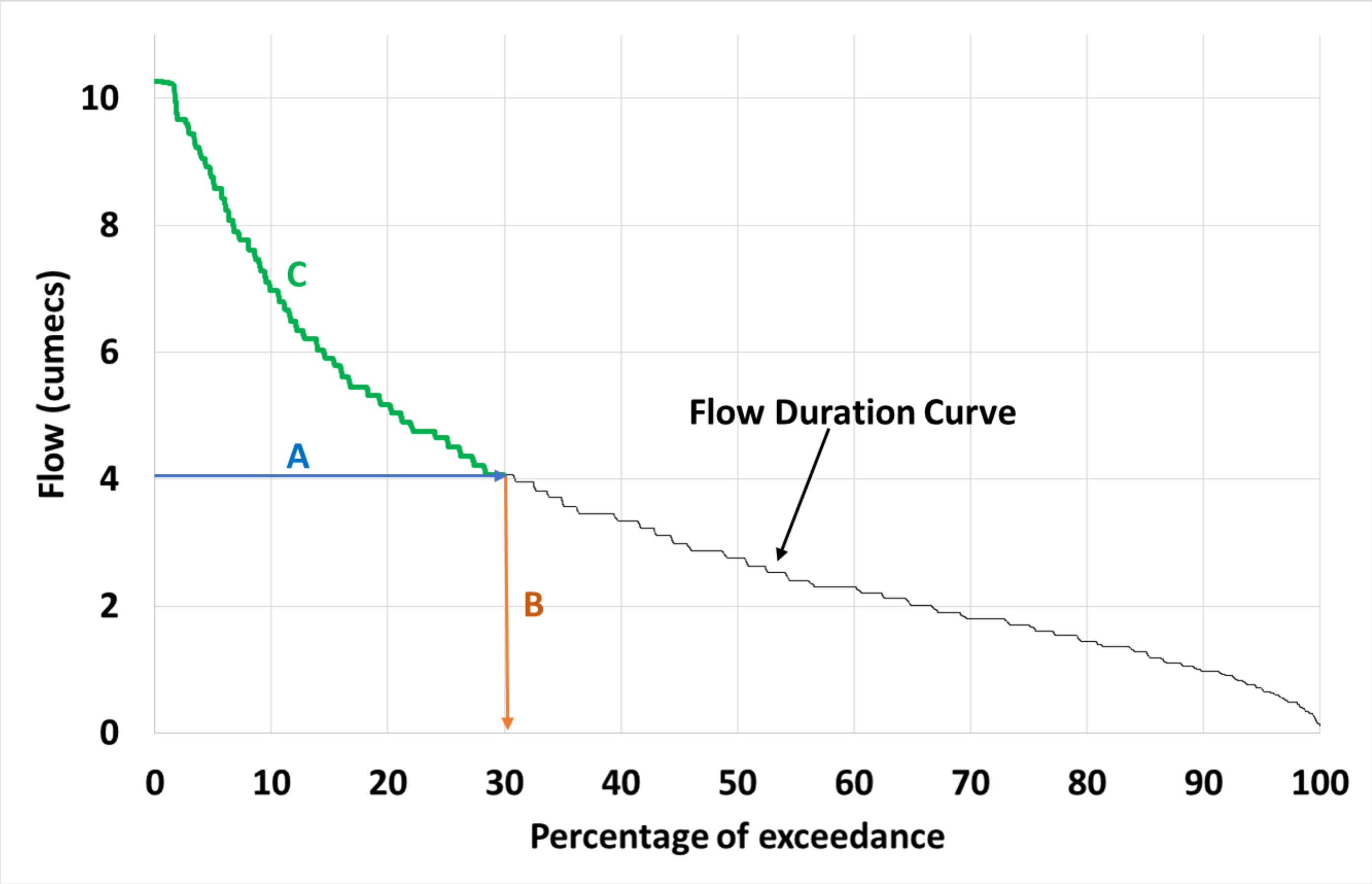
The same method described above can be applied for water quality, the only difference being that we use **concentrations** instead of flow rates. A third type of duration curve also exists, which, is called a **load duration curve**. In the same way, if you have flow rate and concentration information, you can calculate load (load = flow x concentration). We can then rank those loads against the flow at which it was observed, which provides us with a water quality load that has a flow relationship, which can be plotted as a load duration curve. We can then see which loads were observed under which flow conditions. See the OROS example later on.

It is useful to understand duration curves as they are often used to represent flow and water quality.

How to interpret a flow duration curve
Look at the graph below: the **Y-axis = Flow (cumecs)** and the **X-axis = Percentage of exceedance**. An example of the steps taken to interpret and use this type of graph are labelled A, B and C.

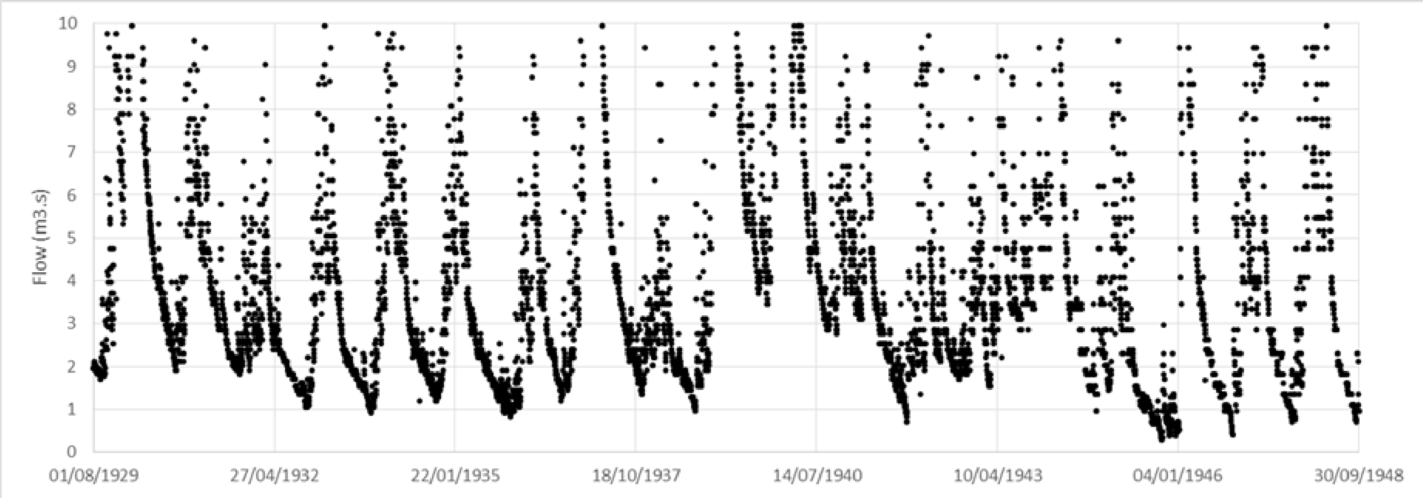
Imagine that someone asks you, "How often is the flow at a point in the river above or equal to 4 cumecs?"

To answer this, draw a horizontal line ('A' on the graph below) from the point on the Y-axis that equals 4 to the point where it touches the flow duration curve, then draw a vertical line ('B' on graph below) down to the point where the line touches the X-axis. The point where the line touches the X-axis give you the answer, which is: the flow in the river at this point is equal to or greater than 4 cumecs 30% of the time (area of the flow duration curve above 30% is represented by 'C'). You could also interpret this as: the flow at this point in the river is equal to or less than 4 cumecs 70% (100%-30% = 70%) of the time.



How to create a flow duration curve
The following steps can be challenging, but being able to create your own flow duration curves helps you to interpret them.
In this handbook we work with **flows**, water quality **concentrations** and **loads,** using duration curves. Flow data for any catchment within South Africa can be downloaded from the Department of Water and Sanitation website:
(https://www.dws.gov.za/hydrology).

The data comes in time series* format (the flow during a **time interval** at a specific place see a plot of a time series below). To develop a flow duration curve, you need to transform and manipulate the time series (see A in table below). The first step is to copy all the observed flow data into a new column (using, for example, Excel) and sort the column from largest to smallest (this is called 'ranking the flow'; see B). Then, in a new column named 'Rank' (see C), rank each flow value (e.g. the first flow will be ranked number 1 as it is the largest flow, the second flow will be ranked 2 as it is the second largest flow, etc.).

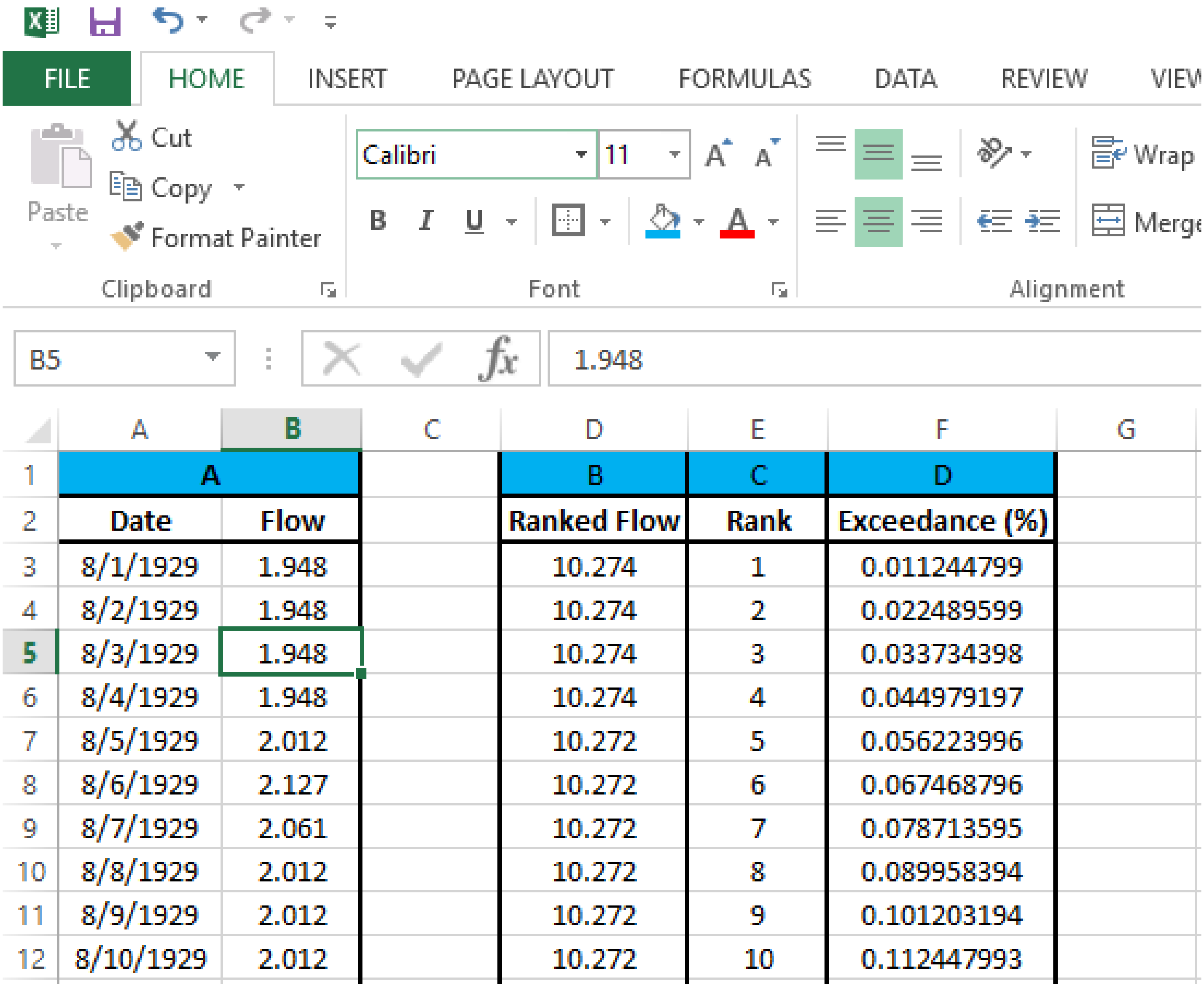


To calculate the exceedance percentile, use the equation Exceedance percentile = current rank / (largest rank + 1) X 100

For example, if you are trying to calculate the exceedance percentile for the largest flow and there are 8892 flow measurements (which is the case in the table below) the calculation would be: 1 / (8892 + 1) X 100. It is necessary to add 1 to 8892 because there is no Rank equal to 0, and you multiply by 100 to convert the fraction to a percentage.

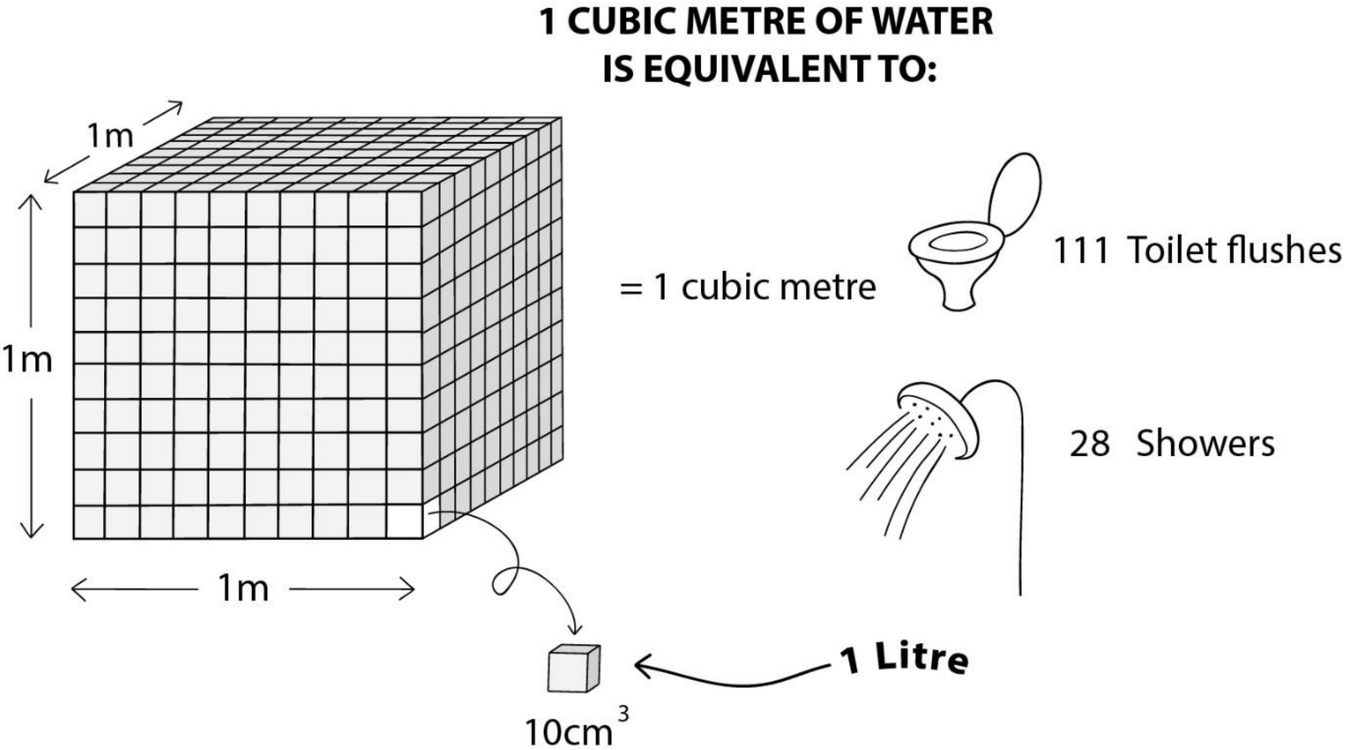
Once you have applied the equation to all the ranks you can create the duration curve plot seen in the graph above.

The X-axis is your exceedance column and the Y-axis is your flow column.
(Remember to plot your graph using a scatter plot, connect the points with a line and remove the markers).



	A	B	C	D	E	F	G
1	A			B	C	D	
2	Date	Flow		Ranked Flow	Rank	Exceedance (%)	
3	8/1/1929	1.948		10.274	1	0.011244799	
4	8/2/1929	1.948		10.274	2	0.022489599	
5	8/3/1929	1.948		10.274	3	0.033734398	
6	8/4/1929	1.948		10.274	4	0.044979197	
7	8/5/1929	2.012		10.272	5	0.056223996	
8	8/6/1929	2.127		10.272	6	0.067468796	
9	8/7/1929	2.061		10.272	7	0.078713595	
10	8/8/1929	2.012		10.272	8	0.089958394	
11	8/9/1929	2.012		10.272	9	0.101203194	
12	8/10/1929	2.012		10.272	10	0.112447993	

How to calculate flow rate

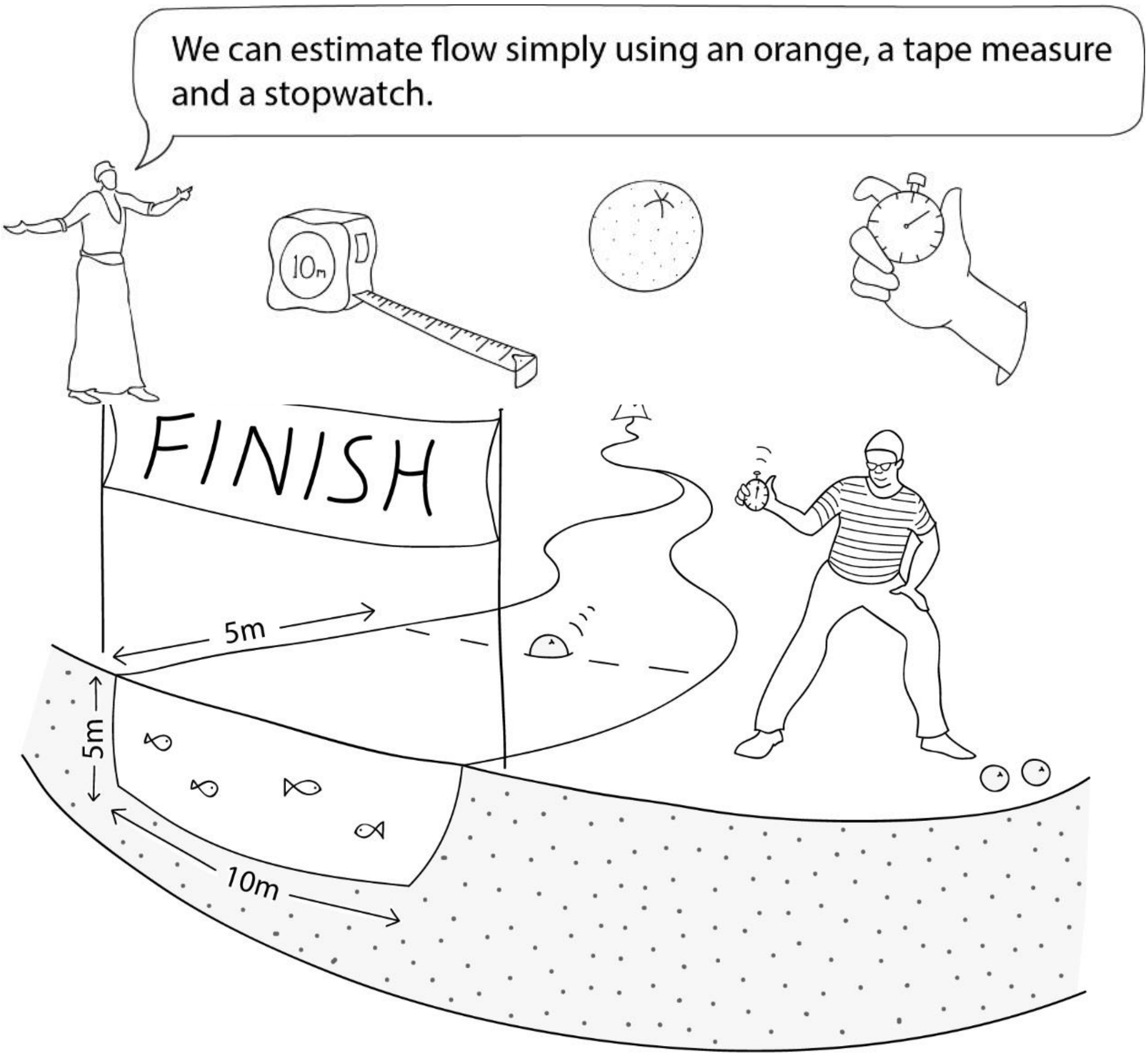


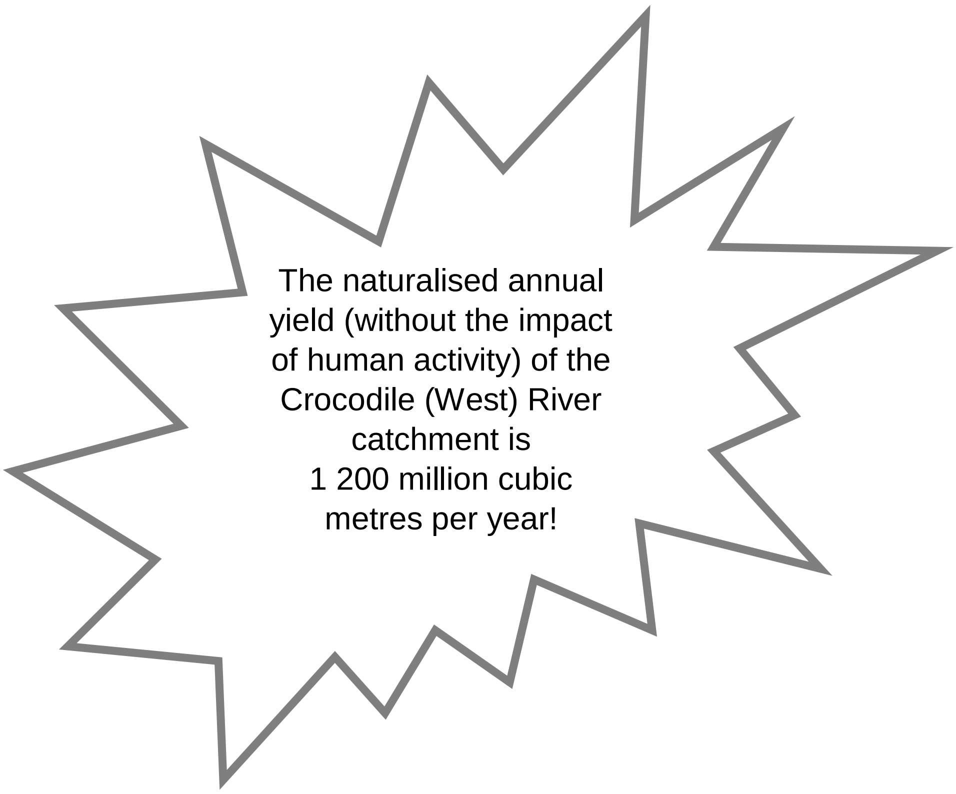
How do we calculate flow rate? Or use it to assess the volume of water available and required to meet human needs and keep ecosystems healthy?
Flow is measured with specialised equipment known as flow probes that are installed in weirs (see above).

A simple alternative:

We can estimate flow simply by using an orange, a tape measure and a stopwatch (see illustration below).
First, mark a point in a river where you would like to know how much flow is passing it every second. Let's call this point the 'finish line'.
Then use the tape measure and measure 5 metres upstream of that point. Let's call it the 'start line'.
Take out the orange, place it in the water at the start line. Start the stopwatch as you let go.
The orange will float down the river and as it passes the finish line, stop the stopwatch.
Let's say it took 2 seconds. We now have the time it took for the orange to travel 5 metres, and if we had to convert this to a speed in metres per second (ms^{-1}) it would = 5 m/2 sec = 2.5 ms^{-1}.
We now have what is called the flow velocity (speed), but we still don't know how much water passed that point in those 2 seconds. To do that we need the missing dimensional property, and, in the case of flow, it would be the area (depth of the river x width of river bed covered in water) of the channel.
So, estimate or measure the average river depth and width. Imagine a river bed 10 metres wide and 5 metres deep; this would give us an area of 50 metres squared (50 m^2). Now multiply the velocity by the area: 2.5 x 50 = 125 cubic metres per second (125 m^3s^{-1}). In litres, this equals 125 000 litres per second.

To calculate the volume of water that would pass that point in 24 hours (1 day), all we need to know is how many seconds there are in a day. There are 24 hours in a day x 60 minutes in an hour x 60 seconds in a minute = 86 400 seconds in a day. So, the total amount of water (volume) would be = 86 400 seconds x 125 cubic metres per second = 10 800 000 m^3 /10.8 million m^3 (Mm^3)/ 10.8 billion litres (10 800 000 000). It makes sense now why we use cubic metres.


We can estimate flow simply using an orange, a tape measure and a stopwatch.
10m
FINISH
5m
5m
10m


The naturalised annual yield (without the impact of human activity) of the Crocodile (West) River catchment is
1 200 million cubic metres per year!

WATER QUALITY

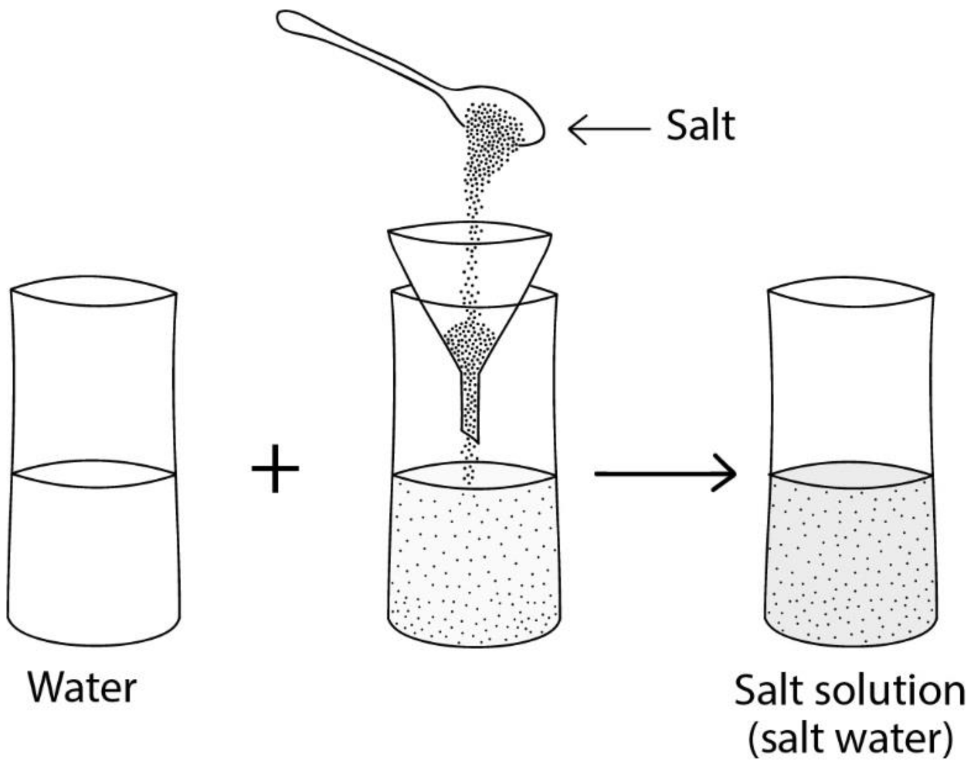
What is Water Quality?

Water quality refers to the **chemical**, **biological** and **physical** characteristics of water, which are often measured and used to indicate the health of an ecosystem, or to indicate whether the water can be used for drinking, industry, or agriculture.

Water resource managers rely on water quality data to monitor the health of rivers, and to keep track of changes in a catchment.

What are chemical, biological and physical characteristics?

Chemical: Everything in our world is a chemical; for example, water is a chemical. However, in water resource management, we use chemical characteristics to describe what is in the water. For example, if we put 1 teaspoon of salt into a glass of water, the salt dissolves, and the salt and water together form a **solution**. Water resource managers talk about the salt, its concentration, its load, and its potential impact on the environment.

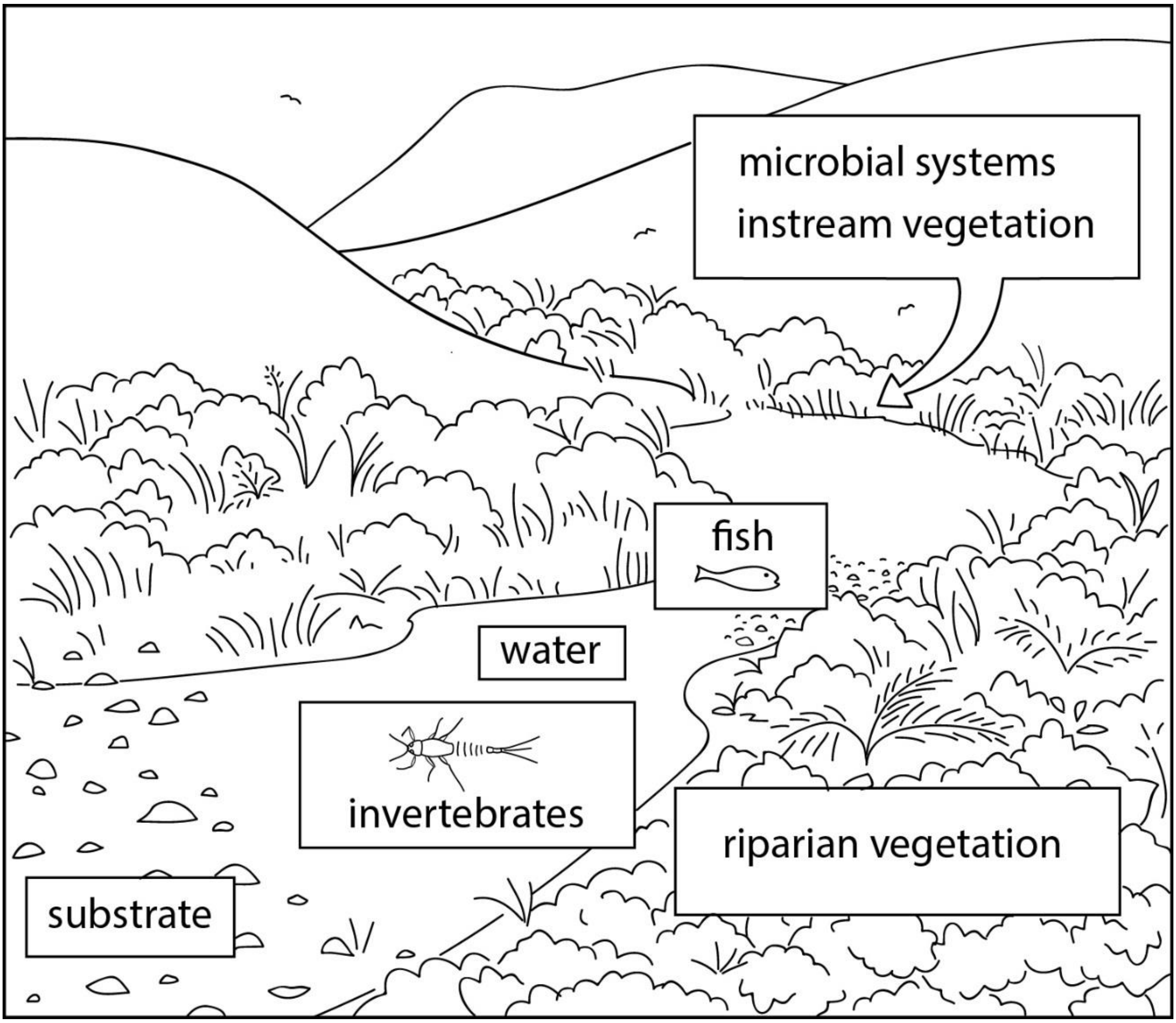


There are different categories of chemical variables, for example, salts (inorganic ions), and organic chemicals, which have a structure based on carbon. Micro-organisms can often break down and process organic compounds, but they cannot process inorganic compounds.

Physical: Two basic physical characteristics of water are temperature and turbidity. Physical factors that affect water ecosystems include substrate, slope, and altitude.

Biological: Anything that is living – including microbes, fish, invertebrates, algae, submerged plants and riparian vegetation.

Some characteristics of an aquatic ecosystem.



Some important water QUALITY words and concepts
The following are some of the most commonly used water quality terms related to water resources management. It is important to become familiar with these terms, as you will often encounter them in meetings/reports/papers and in this handbook. Please refer back to them when you need to.

Bioaccumulation: The process that results in a build-up (accumulation) of substances in the tissues of an organism (bio-). The most common substances that accumulate in organisms in an aquatic environment are metal ions and organic chemicals such as pesticides. They enter the water as a result of mining, industrial, and agricultural activities. A substance bioaccumulates in an organism when the substance accumulates in its body faster than the organism can get rid of it through excretion or catabolism (the process in which the physiology of the organism breaks down a chemical compound).

Concentration: Earlier we used an example of adding salt to water to change the water's chemistry by creating a **solution** (solution = **solvent** (water) + **solute** (salt)). A **concentration** refers to the amount of salt in relation to the amount of water. For example, if we added 10 grams of salt to a litre of water the concentration of salt would be 10 grams per litre (gl^{-1}). The concentration can be changed by either adding or removing salt from the solution, or by increasing or decreasing the amount of water. The concentration of chemicals in water plays a crucial role in keeping an ecosystem healthy. If concentrations of certain chemicals (water quality constituents) are too high, they may become toxic***** to plants, people, fish and/or invertebrates.

Conservative and **non-conservative:** Water quality constituents can be classified into two major groups: **conservative** and **non-conservative** constituents. Conservative water quality constituents remain chemically unchanged as they are transported downstream (e.g. salts). Non-conservative constituents can change chemically over time (e.g. nutrients). Microbes often play a role in chemical transformation of non-conservative constituents.

Environmental fate: Not all of the chemicals that enter water bodies behave in the same way or end up in the same place. Their behaviour and where they end up (the **life cycle of a chemical**) is known as the environmental fate. For example: some heavy metals will latch onto (bind) sediments; then bottom-feeding fish may ingest such sediments; next, the acid in the stomach of the fish may force the sediment to release the metal ions (a process known as mobilisation), and the metals accumulate in the body of the fish (bioaccumulation). A bird may eat that fish and absorb the metals, etc. We can see very quickly that chemicals in the environment, their interactions and their impacts are complex.

Nutrients: The chemicals, nitrogen and phosphorus, are classified as nutrients because they are necessary when plants use sunshine to convert water and carbon dioxide into food chemicals like glucose or starch (photosynthesis). The plants that grow most obviously in response to excess nutrients are algae (which turn water green) and floating plants that clog up water surfaces. Nutrients influence the productivity of all ecosystems, and are key indicators of water quality.

Under natural conditions these nutrients are often in short supply, both on land and in water bodies. However, farmers regularly apply fertilisers to increase the availability of these nutrients so that crops grow better. This leads to the possibility of nutrients entering water bodies through leaching* (through interflow), ground water contamination and surface runoff. The result is an increase, or excess of, nutrients in the water body (a process known as eutrophication*****).

The other major source of nutrients is human waste in the outflow from sewage treatment works. The major management programme to improve the performance of these wastewater treatment works (WWTW) is the DWS Green Drop Programme (Ntombela et al., 2016).

Other nutrients are only required in low concentrations, but are the essential building blocks of life, for example, magnesium which important as it manipulates biological compounds such as DNA, also called micro-nutrients, and include magnesium, potassium, calcium, iron, zinc, copper and others.

Resource water quality objectives: Water quality variables or constituents are ‘good’ or ‘bad’ at different concentrations, depending on who uses the water. Humans, crops, aquatic organisms or specific industrial processes require different constituent concentrations. A set of criteria known as the Resource Water Quality Objectives (RWQOs) are defined by concentration limits for each constituent. The RWQOs take account of the needs of the ‘most sensitive user’. RWQOs are used to describe the observed water quality and are essential when trying to maintain the ecological integrity of water bodies as well as water supply to different users.

How do we measure water quality?

If we look at the definition of water quality again (see above), it is clear that water quality refers to the chemical, physical and biological characteristics of water. Therefore, if we want to measure water quality, we need to measure variables that represent those characteristics. In general, this can be done using three data sources and approaches:

1. **Water Chemistry:**

There are many different variables that can be measured and water resource managers have to choose wisely. Within a catchment, the location and measurements themselves are critical, as the more variables we measure, the more expensive the lab costs are. While all water quality- and chemistry-related variables can be split up into two broad categories (either conservative or non-conservative variables), when we deal with them in catchment water quality management, we group them into three categories:

   a. **Toxic constituents**: including metal ions, pesticides and endocrine disruptors.
   b. **System variables:** including pH, Total Dissolved Solids (TDS), and Total Suspended Solids (TSS).
   c. **Nutrients:** including ammonia, ammonium, nitrites and nitrates, and phosphates.

The Department of Water Affairs and Sanitation (DWS) has a monitoring network across the country through which water quality samples at multiple specific sites (e.g. canals, rivers, reservoirs, etc.) are taken. Generally, they take water samples once a month at each monitoring site with in a catchment, however, the sampling regime (**where** and **what** to measure and how often) depends on many factors:

- **Accessibility** to the site
- **Importance** of the site (e.g. if monitoring compliance, they may monitor more regularly)
- **Budget**
- **Human capital**
- **Staff availability**
- **Land-use activities**
- **Class of the river (read Handbook 2: *How to think about water for people and people for water: Some, for all, forever*)**

A water resource manager needs to take into account all these factors when implementing a monitoring program. So how do we decide what to measure, based on these factors? There is a standard set of variables measured at all monitoring sites – for example salinity, and nutrients. At other sites, where there are upstream polluting activities, additional variables like metal ions, pH, and selected organic pollutants like pesticides, are monitored.

There are costs associated with measuring different substances. Organic chemicals cost more to measure than inorganic ones, so we seldom monitor for pesticide chemicals.

The observed water quality datasets for each catchment in South Africa can be obtained from: http://www.dws.gov.za/iwqs/wms/data/WMS_pri_txt.asp.

There are a large number of water quality variables measured at the monitoring sites and therefore, when working with the data, we prioritise variables. For example, we can use variables such as **sulphates** as an indicator for coal mining or **phosphates** as indicator of Wastewater Treatment Works (WWTWs) performance.

2. **Physical Indicators**

Physical factors are not often routinely monitored. These include temperature and turbidity, and they affect many chemical processes (Dallas and Day, 2004).

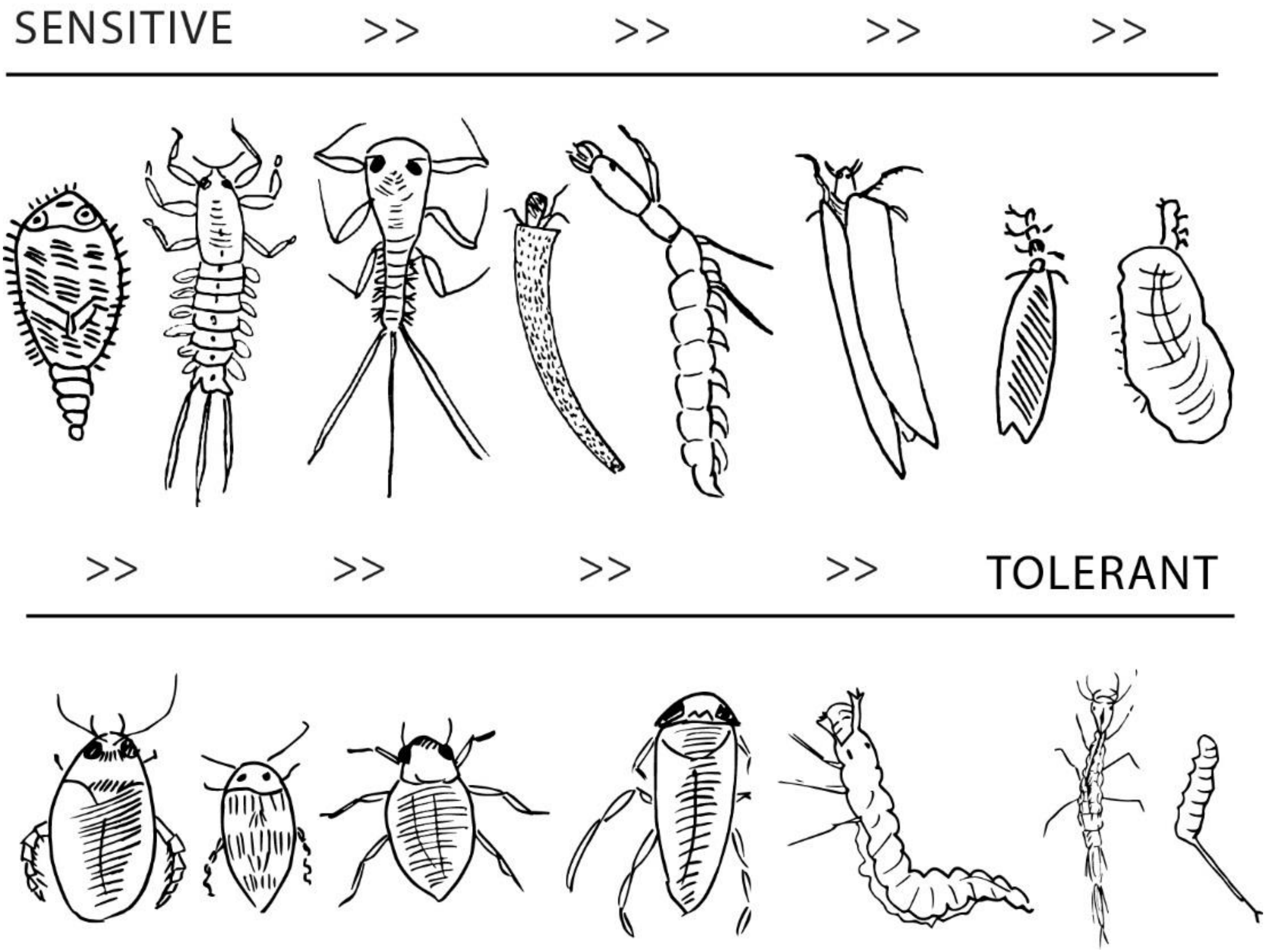
3. Biological Indicators

Healthy rivers are full of living organisms (animals, insects and plants). They are in the rivers for extended periods of time and are, therefore, subjected to conditions (e.g. its physical and chemical characteristics) within the river for that period of time. This is why the living inhabitants of water can be such helpful indicators of the health of the river. Aquatic scientists use specific organisms to determine the health of a river; these include using information about:

- **Fish and macroinvertebrates** (insects living in the water that can be seen with the human eye),
- **Diatoms** (single-celled algae), and
- **Phytoplankton** (microscopic floating algae) **and peri-phyton** (algae attached to a submerged substrate) in the river.

All living organisms respond to the environment, and, depending on conditions, may thrive or die out. Specific organisms may be more tolerant of, or more sensitive to, particular chemicals or physical conditions. The presence, absence and abundance of organisms – the biotic community composition – can therefore be used as an indicator of ‘ecosystem health’.
In South Africa, the tolerance of macroinvertebrate families has been used as an index of pollution. The South African Scoring System (5) (SASS5) is widely used as an ecosystem health indicator. People have generally become involved in citizen science river health monitoring using mini-SASS (http://www.minisass.org/en/).

The illustration on the next page shows the kinds of invertebrates you can expect to find in a river. If the river is healthy, you will find all of them, but in an unhealthy river, only those that are ‘tolerant’ (the ones on the right of the picture) will survive the polluted water.



From Handbook No: 2: How to think about water for people and people for water: Some, for all, forever

How to integrate WATER QUALITY and WATER QUANTITY

This section is relevant for people to want to actually DO water quality-quantity integration.

It is also interesting for those who simply want to understand how integration is possible.

This specialised section includes specific, more detailed references to supporting literature.

Relationship between flow and water quality

What makes the chemistry of water different in different parts of the country? The constituents (or, variables) that make up water depend mainly on how the water moves through porous soils, around rock, over the land surface, and flows in the surface channels of rivers and streams. The chemistry of the land determines the natural chemistry of the water.

In certain cases, vegetation can also influence water quality. For example, the tannins and humic acids* that leach from vegetation of the Cape Floral Kingdom (fynbos) and fall into rivers, result in clear, tea-coloured, naturally acidic water, with high levels of organic compounds. By contrast, the water in the rivers flowing over the ancient Karoo basin which has a mudstone geology, is naturally high in salts and phosphorus. In this way, hydrological processes determine flow pathways which can strongly influence the chemical and physical properties water in rivers and streams.

Water quality and quantity relationships are different, depending on the water quality constituents, and are influenced by the physical characteristics (topography*, soils, geology, vegetation and land cover) of a catchment and the way in which these affect hydrological processes (Malan and Day, 2003; Soulsby et al., 2006; Slaughter, 2011a).

Contributions to natural stream flows can be broadly classified into three components, depending on the hydrological processes through which rainfall becomes runoff:

- surface flow,
- interflow and
- groundwater (Hughes et al*.,* 2003; Soulsby et al., 2006).

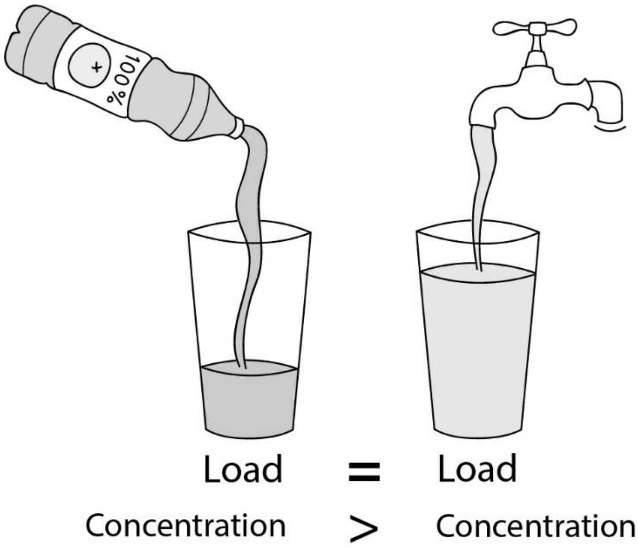
These contributions follow different pathways, have different residence times* and therefore have different natural water quality signatures*. As Hughes et al. (2003) explain, total stream flow is derived from runoff processes, with surface runoff being the source that reacts most rapidly (primarily associated with transient* events, for example a heavy rainfall event resulting in a large quantity of water running over the land surface), interflow reacting more slowly, and the discharge from groundwater being the slowest to react.

As water travels through the catchment within the various flow pathways, the chemistry of the water changes as it comes into contact with various substrates (surface land-use structure*, soils, and geology). In addition to accumulating and transporting chemicals, water quantity plays a major part in the concentration of water quality constituents in-stream, because of a process known as dilution.

Dilution is the process by which water with a low concentration of chemicals mixes with water that has a different concentration of the chemical, which reduces the overall concentration of the chemical in the new mixture.
NOTE! The process of dilution does not change the <u>amount</u> of the chemical in the water only the <u>ratio</u> between chemical and quantity of water.

Fruit Cordial example

A nice example of dilution is the Fruit Cordial juice example (see picture below). If we pour only Fruit Cordial into a glass, there will be a 100% concentration of Fruit Cordial and it will taste extremely sweet (because of the high concentration). If we add water to the glass, the concentration decreases and, therefore, its sweetness. **But,** the amount which we refer to as **load** remains the same.



Transient events

Transient events are usually associated with surface runoff. These events mobilise chemicals that have accumulated on the land surface and carry the chemicals to nearby rivers.

Residence time

The residence time of quality constituents plays a critical role in overall water quality and ecosystem dynamics. When water quality constituents remain in any water body for a long period of time, they increase the overall effect on water quality; for example, in the case of nutrients, plant growth increases, or, in the case of toxic metals, the exposure of biota increases. Brion et al. (2000) found that, in the Seine River (France), because of short residence times, slower growing nitrifying bacteria populations did not have enough time to develop sufficiently to nitrify available ammonium. Where water moves slowly (as in lotic rivers and impoundments), nutrients are trapped and thus are more bioavailable for adsorption* by macrophytes; or the nutrients settle and are bound to sediments. One example of this is the presence of dense alien hyacinth growth in some of the slower-moving stretches of the Crocodile River in South Africa (Deksissa et al., 2004)

Natural processes

Sear et al. (1999) state that, "the form and concentration of dissolved materials in stream water depends on its history of contact". The water quality in surface waters is influenced by a number of processes because of the contact between water and a number of natural elements that may influence in-stream water quality independently, or at the same time. These elements include the climatic conditions in a catchment (geomorphological, geological, soils and vegetation), hydrological conditions (flow regime) and hydrodynamic conditions (rate of river flow) (Soulsby et al., 2006). The resulting processes influence the input of minerals and organic matter (e.g. soils, minerals from groundwater flow, organisms, etc.), and determine the conditions (climate, relief and stream-flow regime) for in-stream chemical reactions (Sear et al., 1999).

According to Day et al. (1998), the underlying geology in South Africa influences in-stream water quality. The geological formations found across a catchment can vary greatly both in age and composition. In South Africa, predominant underlying geological formations are sedimentary rocks of marine origin (Day et al., 1998; Slaughter, 2011a). Geological formations of sedimentary origin consisting of shale (with high $CaCO_3$ composition), for example (Railsback, 1993), weather more easily and water flowing through these rock formations tends to be associated with higher water quality concentrations (e.g. TDS ranging from 195 to 1 100 mg ℓ^{-1}) (Health Canada, 1991). By contrast, geological formations of igneous origin (e.g. basalt, andesite, rhyolite, granite and diorite, etc.) are far less susceptible to weathering because of their composition; their associated water quality signatures are typically lower (generally < 65 mg ℓ^{-1} for TDS) (Health Canada, 1991).

The type of soil found within a catchment can also have a profound influence on surface runoff, interflow and groundwater water quality concentrations (Bronick and Lal, 2005). Both inorganic and organic soil particles have negative charges on their surfaces (Carter and Gregorich, 2008). This allows the adsorption of mineral cations* to soil particles (Bronick and Lal, 2005; Carter and Gregorich, 2008), which are not easily leached out during vertical (recharge)* or lateral (interflow) drainage processes* (Carter and Gregorich, 2008). The soil's ability to attract, retain and exchange cations is known as the Cation Exchange Capacity (CEC), and soils with high clay composition have higher CECs and a greater ability to hold onto nutrients (Figure 2.6) (Carter and Gregorich, 2008).

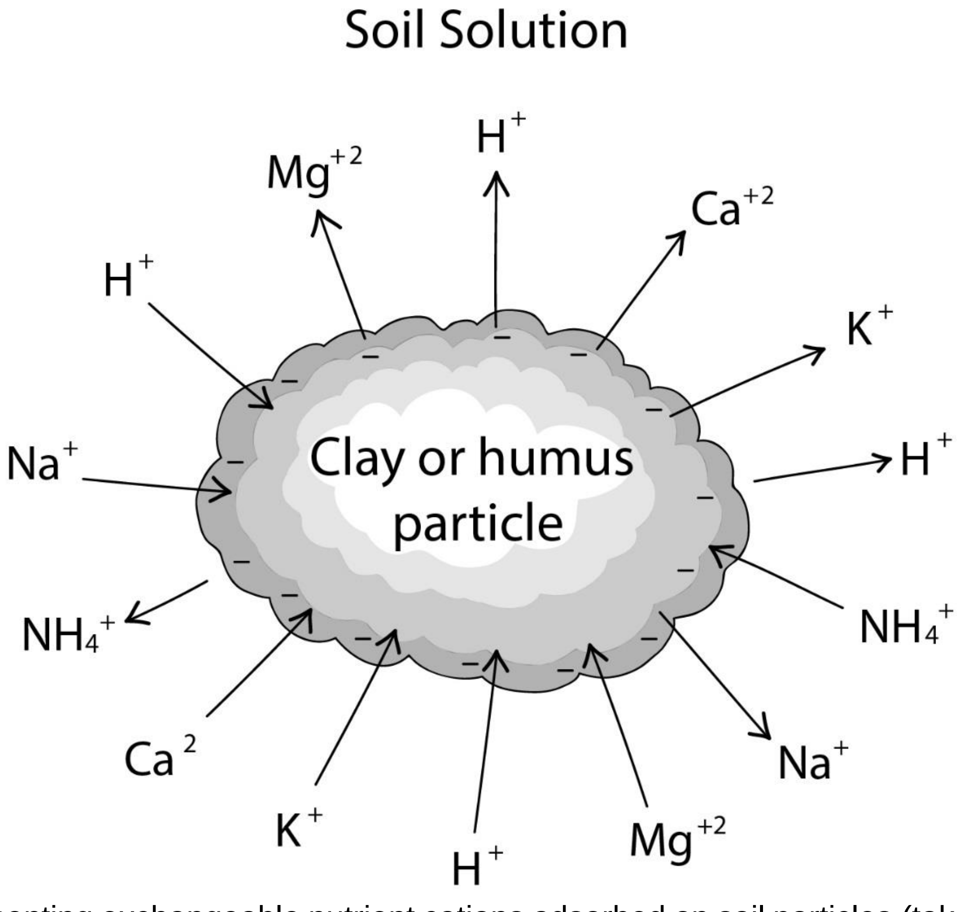


Diagram representing exchangeable nutrient cations adsorbed on soil particles (taken from Nathan, 2009**)**

Anthropogenic* (human-induced) processes

Pollutants from anthropogenic activities enter lentic or lotic water bodies at a specific location within a catchment, but have a range of possible scale outcomes from localised to first order catchment level responses (Johnson et al., 1997). The way in which pollutants enter water bodies varies, but can be broadly classified as point sources or diffuse sources. A point source represents polluted effluent that travels directly from the source to the water body through a channel that is restricted in size (e.g. from a factory via a pipeline to a nearby water body). Diffuse sources are pollutant sources where there is no direct point of input and water is often mobilised and transported by natural hydrological processes, for example leaking sewerage pipes. (Muir, 2011).

Point sources
Point source pollution is frequently believed to be highly predictable because discharge licensing regulations are strict. Therefore, it is assumed that point source contributions will be constant over time. Bowes et al. (2008) found that phosphorus concentrations decreased as flow in catchments (where point sources dominated) increased. They attributed this to a constant input of a pollutant during all flow conditions which was diluted during high flow events. However, Hughes and Slaughter (2013a) noted a great deal variability in nutrient concentrations at low flows, which was attributed to temporally variable effluent releases and effluent concentrations from wastewater treatment works (WWTWs) in South Africa.

Diffuse sources
Diffuse sources are extremely difficult to measure and regulate, and the pollutant load associated with diffuse sources usually varies spatially and temporarily with season, precipitation and other transient events (Malan et al*.,* 2003; Slaughter, 2011a). Anthropogenic diffuse sources include agricultural activities that may result in surface runoff loads, and/or leaching from using manure and nitrogen-based fertilisers, and from cultivating nitrogen-fixing crops.

Other sources, falling under the broad category of urban runoff, include failed septic tanks and runoff from construction sites and abandoned mines, where mine wastewater eventually makes its way into nearby water bodies (Oberholster and Ashton, 2008).

Flow rate and volume influences in-stream water quality concentrations through mobilisation, dilution and/or residence time. Bowes et al. (2008) found that rivers dominated by diffuse sources of phosphorus experience increased water quality concentrations during high flow periods. This is because the mobilisation of phosphorus depends on flow processes, including runoff from urban areas, and/or surface waters draining soils of agricultural areas and entering rivers as interflow with large phosphorus loads (Hughes and Van Ginkel, 1994; Slaughter and Hughes, 2013a). Slaughter and Hughes (2013a) found that, in South Africa, there are frequent increases in concentrations of nitrates, nitrites and phosphates with increasing flows. However, the relationship was found to be highly variable.

In-stream processes
Once water quality constituents have entered a river channel, they are exposed to a number of processes that will determine their environmental fate. The in-stream processes can be broadly classified into:

- hydrophysical processes that influence the transportation of water quality constituents through the processes of convection and diffusion;
- hydrochemical processes, which influence in-stream water quality, include dissolving constituents, sedimentation and adsorption;
- hydrobiological processes. Organisms within the water strongly influence water quality; for example, algae in fresh water systems are major primary producers and play a critical role in the nutrient dynamics of streams.

Working with water quality and quantity data

It is clear that the relationship between water quality and quantity is extremely significant and it is essential to manage both of them together, in an integrated manner.

This section introduces a method of working with observed water quality and quantity data, available from the Department of Water Affairs, Resource Quality Services (RQS) website, and the Hydrology website.

First, we need to understand the catchment and its physical characteristics that may influence water quality, and then work with water quality concentrations and flows to determine loads.

Understanding your catchment

Geology

The underlying geology of the catchment inherently determines the geomorphology and soils, which in turn influence the water quality constituent concentrations (natural background concentrations) found in water bodies.

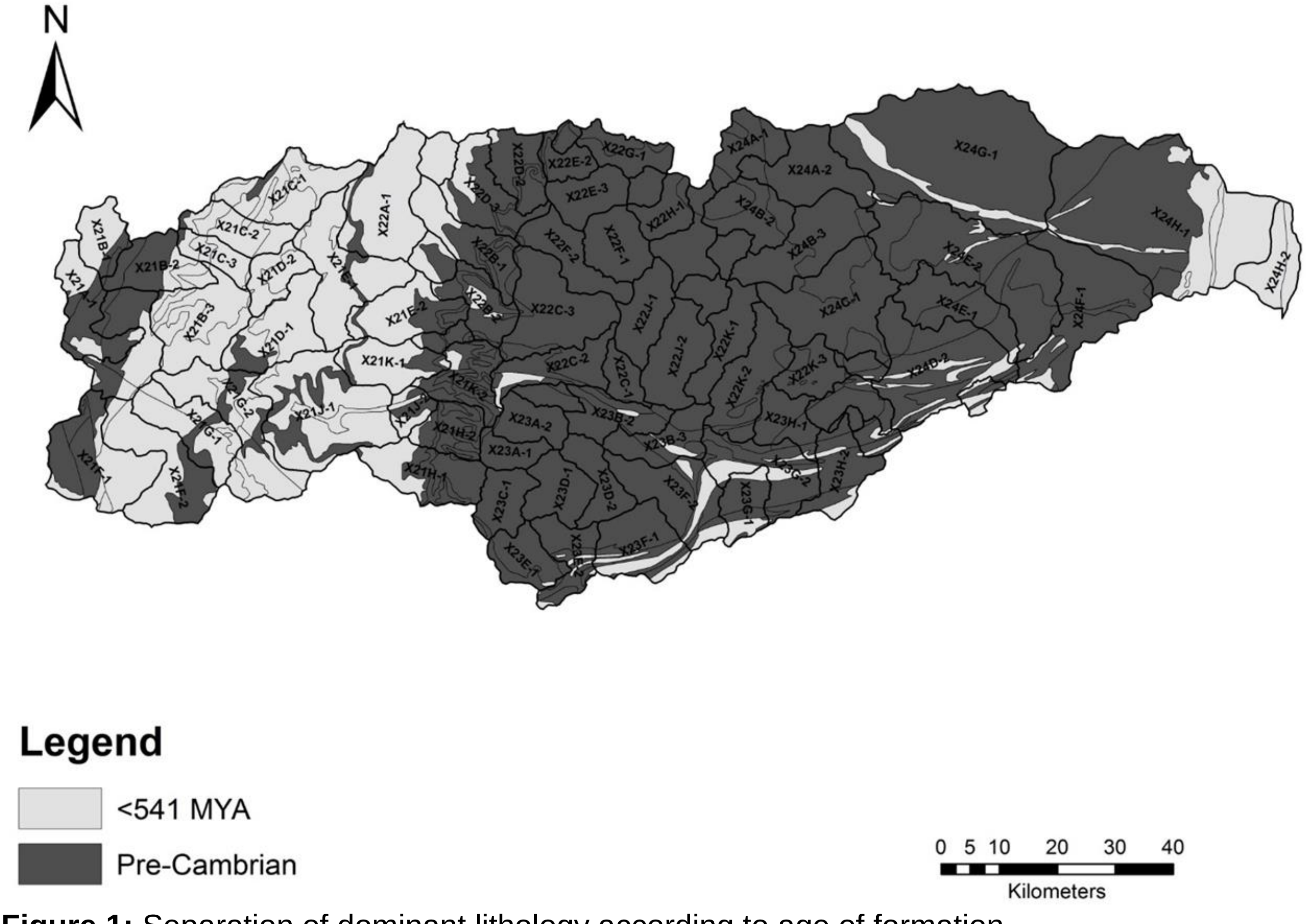


Figure 1: Separation of dominant lithology according to age of formation

Soils

When water moves through soil, the soil has the ability to hold onto minerals. The degree to which it can hold onto minerals is known as the cation exchange capacity (CEC). Soils with a low cation exchange capacity tend to leach more nutrients and other minerals into nearby water bodies, whereas the opposite is true for soils with a high cation exchange capacity.

Table 3.1 Index for soil symbols represented in Figure 2 (below) (based on descriptions from the Soil Map of the World, 1974)

SYMBOL	SOIL TYPE	COMMENT	CEC TOPSOIL	CEC SUBSOIL
AO	Orthic Acrisols	Acidic soils with a layer of clay accumulation. This type consists only of clays with low cation exchange capacity.	7.6	7.5
BC	Chromic Cambisols	Soils with slight profile development that is not dark in colour.	15.7	18.9
FR	Rhodic Ferralsols	Highly weathered soils rich in sesquioxide clays and with low cation exchange capacities.	8.6	4.9
LC	Chromic Luvisols	Soils with a strong accumulation of clay in the B-horizon and not dark in colour. These soils have clays with high cation exchange capacity.	13.1	14.7
QC	Cambic Arenosols	Soils with a strongly bleached layer and a layer of iron or aluminium cemented organic matter.	3.5	3
WE	Eutric Planosols	Soils with a light-coloured layer over a soil layer that restricts water drainage.	8.4	14

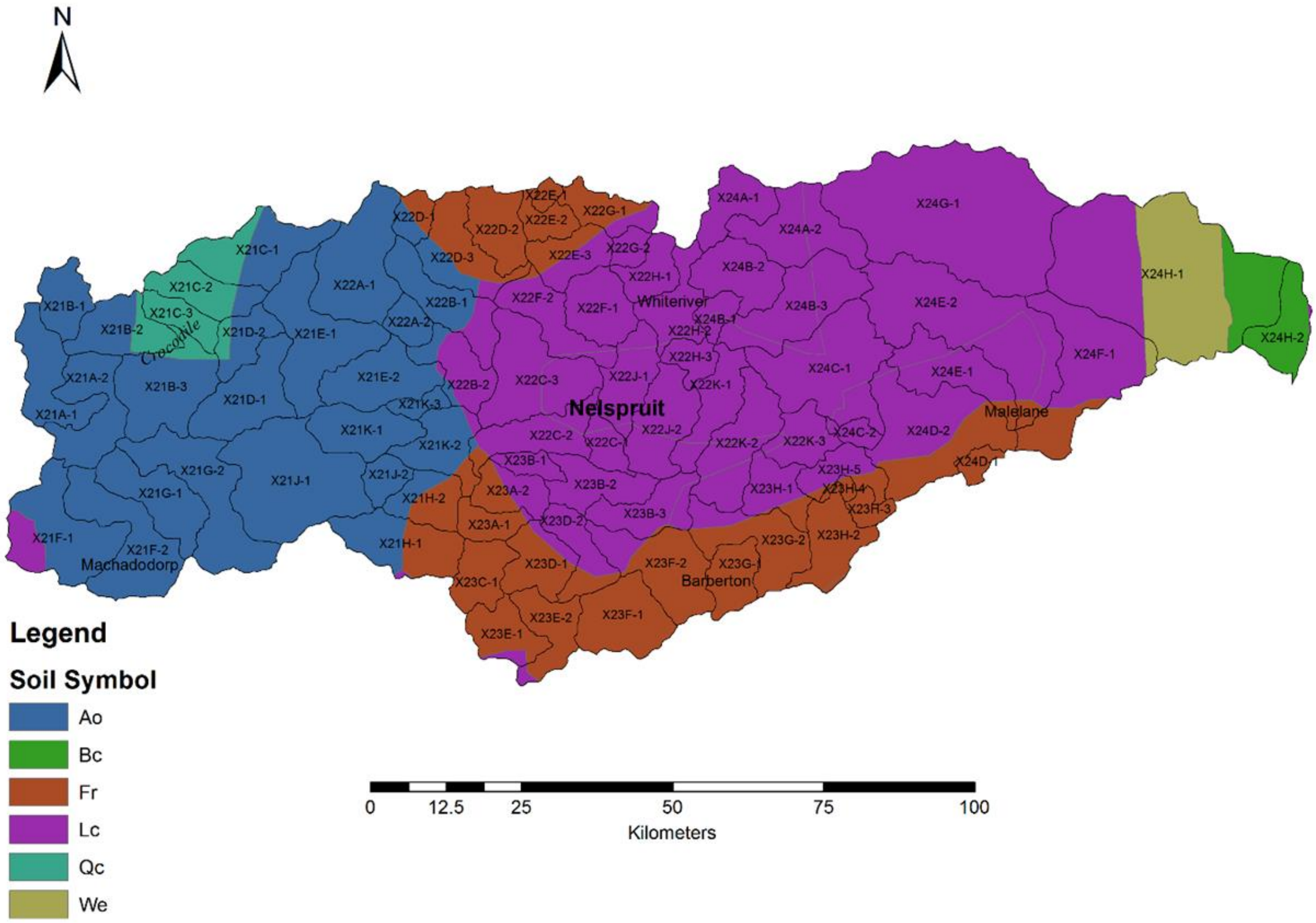


Figure 2: Soils of the Crocodile River Catchment

Topography/Drainage

Topography and drainage characteristics influence the residence time of water quality constituents. For example, the map below shows that the CRC is located within the eastern escarpment of southern Africa, characteristic of rivers draining steep escarpment slopes, then flowing across more gently sloping lowveld terrain.

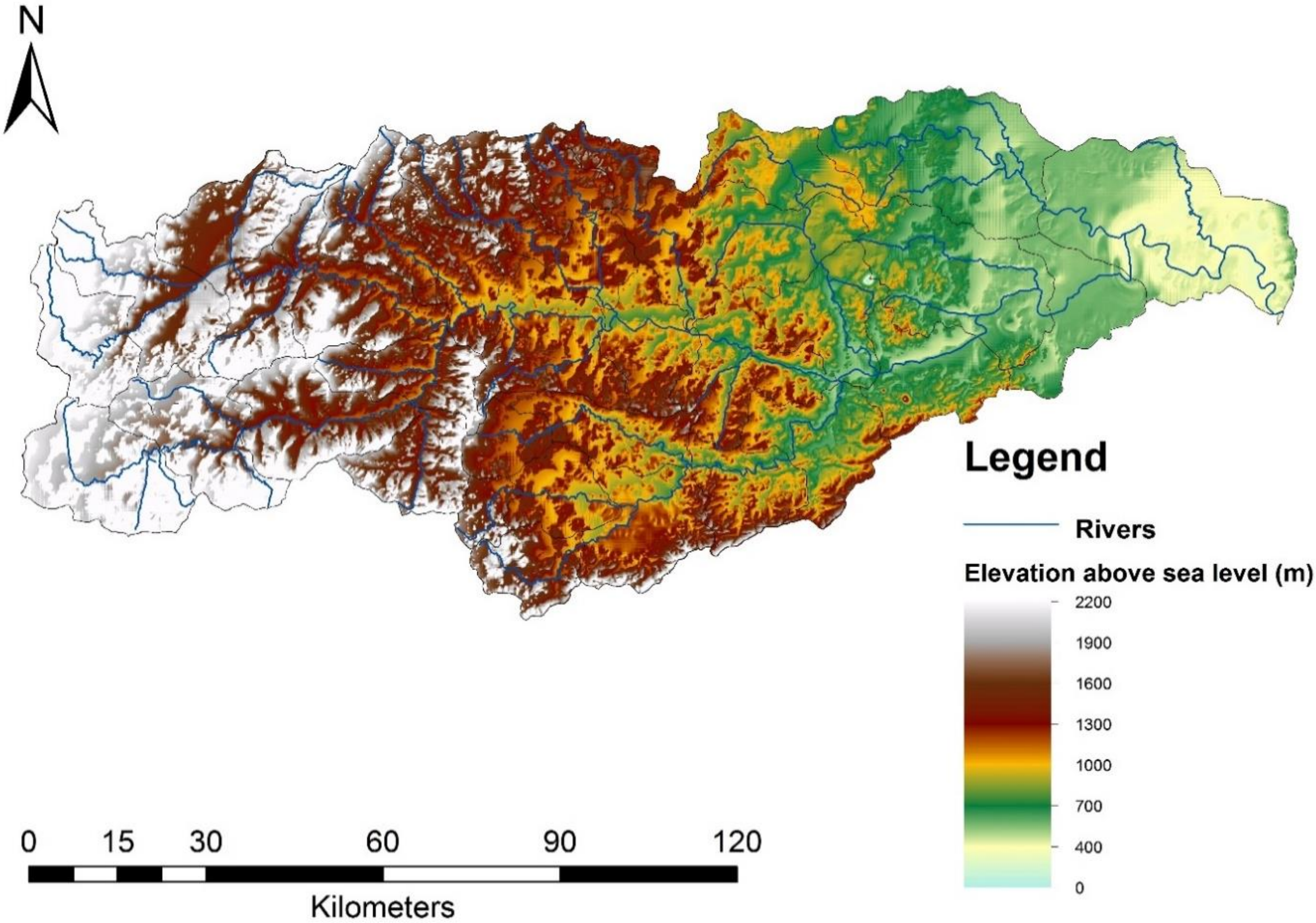


Figure 3 Topography and drainage map of the Crocodile River Catchment

Identifying flow and water quality relationships

The relationships between flow and water quality were described to show how flow has a major influence on the concentration and residence time of water quality constituents in a catchment. Therefore, in this section, water quality and flow data are analysed together in the form of water quality loads. This provides an indication of source loading and dilution capacity of major reaches of a catchment, and helps to identify flow conditions where water quality guidelines are exceeded. Load Duration Curves (LDCs) are a method of representing observed loads as frequency of exceedance distributions, and are based on ranking loads according to observed flow rates.

LDCs are useful tools for analysing the spatial variability of water quality across the catchment, and for representing the flow conditions in which the water quality sample was taken. The flow component characteristically provides a seasonality signature (that is, shows whether the sample was taken during the wet or the dry season) to the water quality observations and, in addition, can help identify the type of source loading to the system (diffuse or point source). Using LDCs as a guideline to water quality concentration (related to human use or ecological requirements) can be expressed as threshold loads (mass) across the entire flow frequency distribution. In this way, LDCs make it possible to link the threshold water quality concentration and the load at different flow rates (and therefore different dilution capacities) before the threshold concentration is exceeded. Bonta and Cleland (2003) suggest that LDCs can be used as a water resource management tool in the Total Maximum Daily Load allocation process, as LDCs indicate the load a polluter can release into a river, taking into account variable dilution capacities of the river at different flow rates.

Creating and interpreting a load duration curve

Please refer back to where we introduce the basics of a duration curve if you are unclear of the basic concepts of a duration curve.

Step 1: Identify all the sites in the catchment where regular flow measurements and water quality samples are being taken and recorded (preferably more than 50 historical samples).
Step 2: Identify all the land-use activities upstream to ascertain which water quality data sets you will require (refer back to [ref to page or paragraph]).
Step 3: Download all the water quantity and quality data sets for the sites identified.
Step 4: Link the water quality data sets to the flow data set (e.g. identify the concentration and its associated flow, see table below). As water quality is not measured on a daily basis we use #N/A to signify no data for that specific day.

Date	**Observed TDS (mg/L)**	**FLOW (cumecs)**
26/06/1977	#N/A	0.879
27/06/1977	#N/A	0.808
28/06/1977	81.9	0.691
29/06/1977	#N/A	0.639
30/06/1977	#N/A	0.525
01/07/1977	#N/A	0.556
02/07/1977	#N/A	0.588
………………..		

Step 5: Calculate the load associated with each flow and concentration. This is done by multiplying the concentration by the total volume of water that passed by per day at the weir. Please refer back to see how a flow rate is converted to a daily volume. The equation to calculate the total weight in tons of a pollutant to pass by per day is:

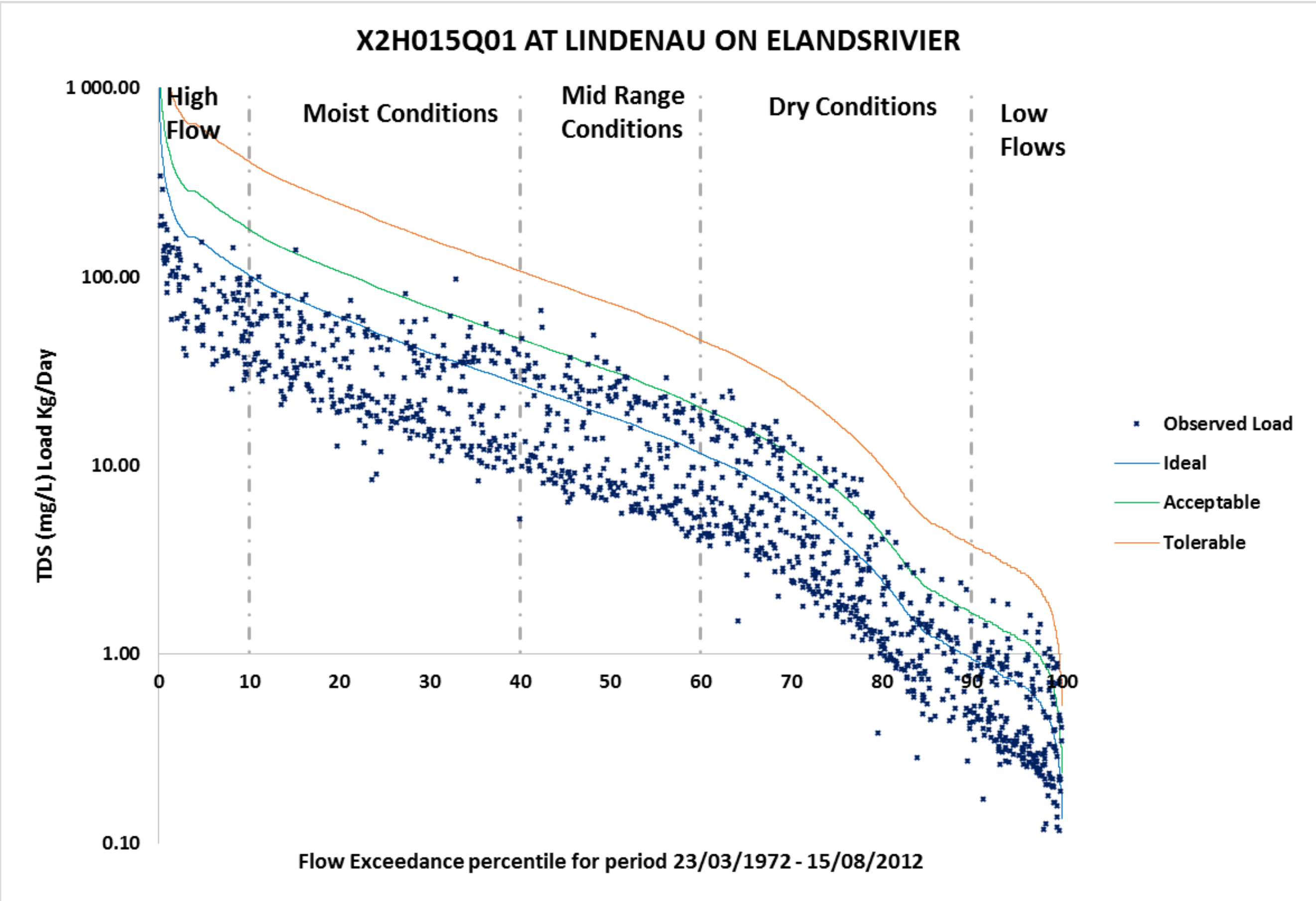
load (tons) = **concentration** x **flow rate** x **conversion factor**
(for tons conversion factor = 0.084, for kilograms = 8.4).

Step 6: Calculate the load limits. This is achieved by multiplying the water quality standard concentration and the conversion factor (e.g. a Resource Quality Objective concentration) by each observed flow record.

Step 7: Rank the observed flow from largest to smallest, ensuring that the loads remain linked to their individual associated flow (see below).

B	C	D	E	F	G	H
Rank	FLOW	Ideal Load	Acceptable Load	Tolerable Load	Observed Variable Load Kg/Day	Exceedance
34	42.83	719.48	1259.08	2877.91	#N/A	0.16132093
35	42.64	716.32	1253.56	2865.27	344.55	0.16606567
36	42.23	709.48	1241.59	2837.92	#N/A	0.1708104

Step 8: Plot the Load Duration Curve (LDC), in the same way as we plotted the flow duration curve (FDC). The only difference is that you do not plot the flow; instead, plot the load (Y-axis) vs Exceedance (X-axis). The result should look similar to the example below:



Step 9: Interpreting the Load Duration Curve.

The load duration curve above shows all the observed loads represented as blue markers, with the ideal, acceptable and tolerable loads plotted as lines (e.g. if the load is above the acceptable line but below the tolerable line we can see that the load falls within the tolerable band).

Load duration curves are so useful because it is possible to plot the loads on the duration of the observed flows. This allows us to separate the load duration curve into its hydrological components: as can be seen above, we can split the curve into high flow, moist, mid-range, dry and low-flow conditions. This makes it possible to distinguish between point source and diffuse source water quality contributions. These load duration curves can also be used to determine by how much loads need to be decreased during certain hydrological conditions (e.g. low flows as experienced during droughts to meet set standards. This is an extremely useful method for managing seasonal loads, especially in areas where flows are driven by seasonal rainfall because it is then possible to have dynamic discharge standards rather than static standards.

Conclusion

In conclusion, the **quantity** and **quality** of water is complex and greatly interlinked, and therefore, one should never attempt to manage the one aspect in isolation, or in the absence of the other. While water quantity data is widely available in the form of long-term records, this is not true for water quality data. However, using both water quality and quantity data together can provide insights into the source of water quality loads and its behaviour. Water resources managers are advised to use water quality and quantity models, such as the Water Quality Systems Assessment Model (WQSAM), in combination with observed load duration curves to fill in the gaps. Such applications would include:

- assessing license applications;
- assessing flow regime changes (using the daily disaggregation method);
- calculating water quality loads produced by sub-catchments;
- identifying periods of concern;
- setting dynamic monthly target loads;
- focussing management efforts;
- assessing management scenarios;
- identifying over-allocated sub-catchments, and reassessing licences in these areas;
- providing insight into climate change impacts on water quantity and quality.

GLOSSARY

adsorption – the process by which a surface holds onto molecules as a thin layer; imagine a magnet holding onto iron filings.

anthropogenic – related to or resulting from the activities of human beings on the environment.

aquifers – underground permeable (allows water to penetrate it) rock formations that store and release water.

geochemical and isotope tracer studies – the process of using stable isotopes (usually a radioactive element like Technetium (Tc)), which is easily detectable. For example, imagine someone releasing a balloon (or in our case water) into the sky with a note (our isotopic tracer); we release the balloon and if someone finds it, they then call us and we can find out where it travelled to.

humic acid – a major organic constituent of many upland streams, dystrophic lakes, and ocean water. It is produced when dead organic matter decays naturally.

lateral (interflow) drainage processes: the movement of water through the interflow zone horizontally towards a stream.

leach – to drain minerals and nutrients away from the soil

mineral cations – the positive form of a mineral (naturally occurring inorganic substance), which is attracted to anions (negatively charged particles)

residence times – the period of time that water remains in the same place (e.g. in a dam).

signatures – just as humans have our own unique signatures, so does water quality. For example, an agricultural return flow is often identifiable by high concentrations of nutrients (predominantly nitrites and nitrates).

stage height – the height of the water in relation to a specific structure of a weir

substrate-driven hydrological processes – the interactions between the flow of water and its contact with substrate (e.g. easily weathered sedimentary rock formations like lime stone).

surface land-use structure – land-use which is often mistaken as landcover refers to the anthropogenic use of land (e.g. areas under agriculture). The surface landuse structure refers to all the different landuse activities that are found in a catchment.

time interval – the spacing of an activity over time, e.g. sampling water quality every month.

time series – a string of data that was gathered over a period of time at either regular or irregular intervals.

topography – the way in which the natural and artificial (e.g. buildings and farms) are arranged in an area.

toxic – refers to a water quality constituent at a specific concentration that is not healthy for a system

transient – lasting for only a short time; temporary (e.g. a large storm followed by a short intense surface runoff event).

vertical (recharge) drainage processes: opposite of the lateral movement (see above), this is the process by which water moves downwards from the surface through the interflow zone replenishing (recharge) the ground water stores.

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