GUIDELINE TO DEVELOP A SUSTAINABLE URBAN RIVER MANAGEMENT PLAN

Report to the Water Research Commission

by

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EXECUTIVE SUMMARY

Nemai Consulting was appointed by the Water Research Commission (WRC) to generate a '***Guideline to Develop a Sustainable Urban River Management Plan***' (SURMP). The study intends to create a guideline document to aid the compilation of a plan that addresses the impacts and management of specifically urban rivers.

Salient themes surrounding urban rivers, such as pollution and impact sources and the concomitant effects, are discussed in the bulk of the document. The document culminates in a guideline which navigates the reader through the steps required to prepare a SURMP.

Section B presents the findings of a research expedition on 'urban rivers' and their inherent characteristics. Although this section by no means exhaustively describes urban rivers, it sets the scene for the detailed examinations to follow.

Section C examines the **water quality** of urban rivers. This section commences with exploring the effects of urban land uses (i.e. agriculture, industry, mining, commercial, residential and recreational) on water quality. Thereafter, the management of water quality is discussed under considerations for water quality appraisal and the subsequent management measures required to address the variables of concern.

The topic of **Section D** is the **socio-economic** context of urban waterways, and the discussions focus on pertinent socio-economic uses of urban rivers, as well as the related issues and their management. Salient aspects examined include dense settlements, public health, recreation and economy.

The interaction between **urban agriculture** and urban watercourses constitutes the theme of **Section E**. The section provides an overview of the impacts of urban agriculture on an urban watercourse, with the impact sources including irrigation, fertilizer and pesticide application, land preparation, grazing, animal waste and dams. Management aspects include the impact assessment and management through the implementation of the relevant statutory provisions as well as general control measures.

Section F investigates the sources of pollutants in **stormwater**, and the impacts of stormwater on urban rivers, which is discussed under sedimentation, flooding and accumulation of litter and other waste. Assessment considerations for flooding are expanded upon under the delineation of flood zones and application of hydrological techniques. Management of stormwater is discussed under the associated legal framework, planning principles and stormwater management measures.

The relationship between urban watercourses and **industry** receives attention in **Section G**. The categories and effects of industrial pollutants are discussed under temperature, pH, turbidity, organic pollutants and other chemical substances in industrial wastes. General management considerations for industry pertain to enabling legislation, water consumption, self-regulation and effluent quality and treatment.

Section H defines **waste** in an urban river context by exploring the impact sources and effects of physical, organic and inorganic waste. Assessment tools discussed include calculating the total litter loading and chemical, physical and biological monitoring. Management of industrial-related impacts to urban rivers are discussed under the associated legal backdrop, waste management principles, managing waste from dense settlements and general management tools.

Section I comprises the **guideline** to develop the SURMP and it offers an approach to managing an urban river by packaging catchment information and available assessment and management techniques into a toolbox for easy use by the guideline user. Section B – H act as supporting documentation for the guideline, and they focus on some of the primary features which influence the state of urban rivers. The main target audience of the guideline is those municipal departments tasked with overseeing urban catchments within their jurisdiction. The guideline navigates the reader through five main elements for preparing the SURMP, namely.

1. The **<u>general details</u>** of the urban river;
2. The **<u>character</u>** of the urban river;
3. The **<u>pressures</u>** associated with the urban river;
4. The **<u>values</u>** of the urban river; and
5. The **<u>management</u>** of the urban river.

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Nemai Consulting was appointed by the Water Research Commission (WRC) to generate a '***Guideline to Develop a Sustainable Urban River Management Plan***' (SURMP). The study intends to create a guideline document to aid the compilation of a plan that addresses the impacts and management of specifically urban rivers.

For the purposes of this study, an urban river is defined as *that reach or section of a water resource located in a catchment which contains a town or a city, where the structure and function of that water resource is altered from its natural state*.

Although rural watercourses are not exempt from anthropogenic influence, a myriad of stresses are exerted on the waterways which fall within urban catchments. The challenges posed with the management of these urban rivers prompted this study.

Salient themes surrounding urban rivers, such as pollution and impact sources and the concomitant effects, are discussed in the bulk of the document. These sections aim to acquaint the reader with some of the notable characteristics of urban rivers and the factors which influence their often degraded state. Many of the elements of these topics, in particular those sections dealing with impacts and management, overlap. Each section should however be seen as a specific examination of the various influences and aspects pertaining to urban waters.

The document culminates in a guideline which navigates the reader through the steps required to prepare a SURMP.

2. AIMS

The aims of the document are as follows:

- **Sections B-H**:
  - ➢ To provide background information on certain key aspects regarding urban rivers
  - ➢ To provide examples of some of the points of discussion through the exploration of case studies
- **Section I**:
  - ➢ To assist practitioners in the urban river field to generate a plan for the sustainable management of urban waterways
  - ➢ To articulate a consistent approach for local authorities (i.e. municipalities) to undertake urban river management

3. METHODOLOGY

The methodology employed during the compilation of this document consisted of the following activities:

1. Comprehensive literature research on various topics related to urban watercourses;
2. Personal interviews with key stakeholders and knowledgeable parties; and
3. Examination of urban rivers though the use of case studies. Two urban rivers were investigated, namely the Upper Jukskei River and the Klipspruit. The Upper Jukskei River flows in a predominantly northwest direction through the northern parts of Johannesburg, as shown in **Figure A.1**. The catchment of the Klipspruit stretches from the south-western part of Johannesburg Central Business District in the east, to Roodepoort in the west and Kliptown to the south, approximately 196 km^2 in area (refer to map contained in **Figure A.2**). Where reference is made to the case studies, grey text boxes have been included in the document.

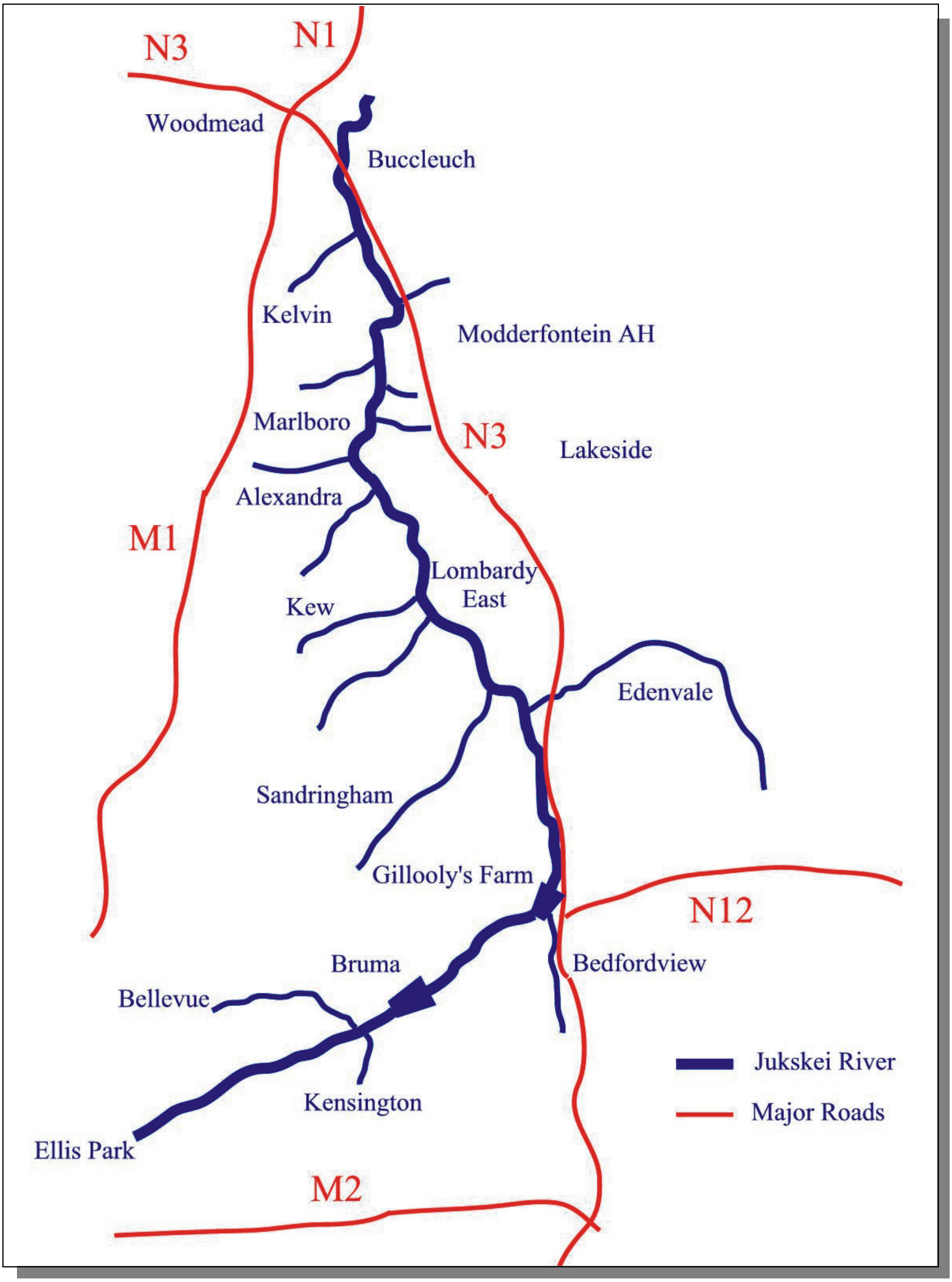


Figure A.1: **Map of Upper Jukskei River's main stem**

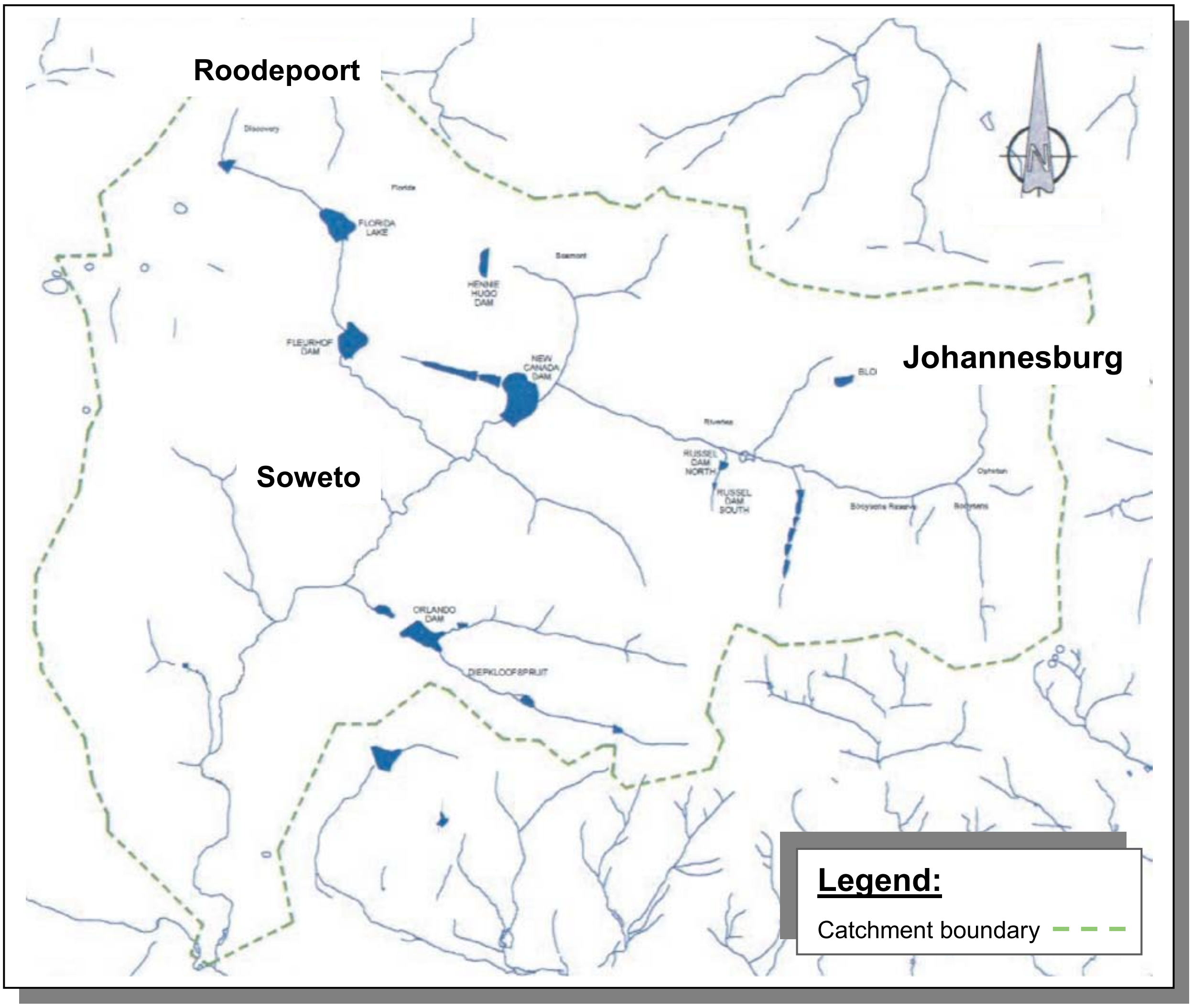


Figure A.2: **Map of Klipspruit Catchment**

4. ASSUMPTIONS AND LIMITATIONS

To some extent, water resource management is considered a dynamic field with regard to the range of assessment and management tools available to practitioners. This is particularly as a result of the changes in the legal framework governing this discipline. It is assumed that certain documents and tools mentioned in this document may thus be replaced as progress is made in some of the associated fields.

The sections leading up to the guideline primarily serve as background information and do not provide comprehensive discussions on the related themes.

B. URBAN RIVER PROFILE

1. INTRODUCTION

As a logical point of departure, the project commenced with a research expedition on 'urban rivers' and their inherent characteristics. **Section B** presents the findings of this inception task.

Although this section by no means exhaustively describes urban rivers, it sets the scene for the detailed examinations to follow. These, in turn, will lead to the development of guidelines to acquaint the intended end-users with urban rivers and steer them on how to prepare a SURMP.

2. ATTRIBUTES OF AN URBAN RIVER

2.1. Introduction

According to the World Resources Institute (WRI) (1996), more than half of the world's population (± 3.3 billion) will be living in urban areas by 2006. Natural resources within urban settings are for the most part in a poor state, with anthropogenic influence as the driving force behind environmental degradation.

Rivers which traverse urban areas are certainly not exempt from the abovementioned hard reality. McWhinnie (1971) refers to 'urban water' as "a term to cover all water in the urban area, including water supply, storm and sanitary sewage, flood control, ground and surface streams, reservoirs, recreation aesthetics and the environment". On the whole, it thus encompasses water from the time it enters the urban area, either as rainfall or inflow (McWhinnie, 1971). As mentioned previously, in this document an urban river is defined as "that reach or section of a water resource located in a catchment which contains a town or a city, where the structure and function of that water resource is altered from its natural state".

Initial human settlements are frequently located on a stream, for reasons of water transportation, power, water supply, convenient drainage and waste disposal, or other reasons (Whipple, 1974). A host of impacts, primarily dictated by surrounding land-use and the urban fabric, render urban waterways as severely impoverished.

According to Lazaro (1979), urbanisation consists of four stages, namely (1) rural, (2) early urban, (3) middle urban and (4) late urban. The extent to which an urban catchment is detached from its natural state will greatly depend on the level of urbanisation, as well as the competent management of the overall environment.

Humans have strived to manage urban waters for various reasons, ranging from the watercourses' potentially hazardous character (e.g. flooding, pathogens) to their ability to provide recreational appeal to a city's residents.

The dynamic nature of water however poses difficulties in its utilisation and control (Lopes, Jergman and Aswathanarayana, 1991). Many attempts at urban river management have faltered due to the neglect of taking the aforementioned fact into consideration.

Apart from human population numbers, what distinguishes an urban river from its rural counterpart? What attributes shape an urban river? **Sections B 2.2-2.5** (below) will aim to respond to these aforementioned queries in the form of a succinct discussion on the physical, chemical, biological and socio-economic characteristics of an urban river.

2.2. Physical Attributes

Urban development goes hand-in-hand with physical alterations to the environment. A river endures a multitude of changes to its physical make-up as human activities increase in the affected catchment.

During urbanisation, changes to a river's basin include topographical modifications when new landforms are created, and the generation of impervious surfaces as land cover. These practices lead to hydrological changes, which include alterations in runoff movement, total runoff and peak-flow characteristics (Hardoy, Mitlin and Satterthwaite, 2001).

Reduced infiltration due to impermeable surfaces makes groundwater recharge smaller than prior to urbanisation (James and Niemczynowicz, 1992). This disrupts the semi-equilibrium which, according to Stephenson (1992), exists between precipitation, runoff and infiltration into the ground.

Resultant strong flows and floods adversely affect the geomorphology of urban rivers. Erosion of the beds and banks alter an urban river's width and depth, and increases streambank slopes. Urban flows further reduce the sinuosity (i.e. a measure of the amount of a river's meandering) of a river, creating straighter channels.

Impacts on the flow regime of an urban river demand intervention, which is customarily in the form of engineering modifications. Consequently, an urban channel size is frequently a product of channel engineering, and often contains artificial structures (refer to **Figure B.1**) and materials which have significant hydraulic impacts (Environment Agency King's College London University of Birmingham and HR Wallingford Ltd, 2003). In severe instances, urban rivers are canalised (refer to **Figures B.2** and **B.3**) or diverted to minimise flood risks and manage stormwater.

Utilisation of freshwater leads to further impacts on urban watercourses, where water uses include agriculture, domestic, industrial, irrigation, mining, power generation, fish and support to wildlife reserves, navigation and recreation. In South Africa, agriculture accounts for roughly 73% of the total amount of the water used, through mainly water abstraction (O'Keeffe, 1986). This phenomenon applies on a global scale, where Speidel, Ruedisili and Agnew (1988) identify agriculture as the major water user worldwide.

Urban water demands may lead to significant reductions in water quantity, which are met by increasing abstractions from rivers and then by river regulation using dams and reservoirs. Where the provision capacity of a local river is exceeded, water transfer schemes are inevitably undertaken. Leaky pipes, illegal connections and improper use further exacerbate water shortages in urban areas.

CASE STUDY

Figure B.1: **Man-made structure (i.e. gabions and a weir) in the Jukskei River, Johannesburg**

Figure B.2: **Canalised section of the Klipspruit in a residential area, Johannesburg**

CASE STUDY (continued)

Figure B.3: **Headwaters of the Jukskei River (Johannesburg CBD), flowing within a canal**

2.3. Chemical Attributes

Cheng, Yang and Chan (2003) note that urban water quality is strongly influenced by population density, water shortages and pollution. The later encompasses a wide array of root causes, which can be separated into point (e.g. from effluent) and non-point/diffuse (e.g. from runoff) pollution sources. Where point sources are easily detected, accurate deductions of diffuse pollution sources remain challenging.

Urban impacts on water quality are closely linked to the surrounding land use. Ashton and Bhagwan (2001) list the following features of the land use that could be related to the variation of pollution levels observed in runoff:

- Predominant land-use type;
- Nature of development;
- Densities of development;

- Development standard/cost; and
- Levels of services provision and maintenance.

Urban catchments convey a host of pollutants to the receiving water bodies. Vesilind and Peirce (1983) identify industrial wastes as probably the greatest single water pollution problem in the United States, with municipal waste second in importance. This scenario will more than likely shift when an urban river in a third world country is considered.

Urban agriculture may lead to the addition of sediment, pesticides and organic substances to the affected catchment. Associated with mining is siltation and acid-mine drainage. **Figure B.4** presents and urban river exposed to both these notorious mining impacts.

CASE STUDY

Figure B.4: **Russell Stream traversing mining grounds, Johannesburg**

Proper water, sanitation, waste management and electricity are essential human needs in an urban setting. Lack or absence of these services and inefficient maintenance lead to urban water pollution, of which sewage contamination is arguably the most pressing and common.

Anthropogenic activities in urban complexes, such as thermal pollution, stream regulation and changes in riparian vegetation (e.g. loss of canopy cover) cause temperature changes in river systems (Dallas and Day, 1993). The resultant effects are primarily of a chemical (e.g. decreases dissolved oxygen solubility, increase in biotic toxicity of certain chemicals) and biological nature.

Of the many insidious pollutants encountered in watercourses, which are caused by urban activities, some of the most pervasive include silt, nutrients, trace metals and biocides.

2.4. Biological Attributes

Urban environments have greatly digressed from their original pristine state, with ensuing negative outcomes to the natural features of urban watercourses.

Any pollution arriving into the environment influences the ecosystem through individuals of the microbial, plant and animal population (Salanki, 1986). The poor biodiversity of urban rivers is reflected in the lack or altogether absence of fauna and flora species which would be expected to occur under natural conditions. This often leads to the proliferation of resilient species, which are able to tolerate inhospitable surroundings.

According to Naiman (1992), pressures in catchments usually manifest measurably in aquatic habitats. Changes in the flow regime of urban rivers alter the physical environment, which include in-channel aspects of habitat type (riffle, run and pool), substrate quality, and food and cover availability.

Urban-related pollution affects aquatic animals and plants by adding chemical (e.g. organics, toxic metals), physical (e.g. pH, temperature) and biological (e.g. micro-organisms, exotic vegetation) stressors to the freshwater system.

Included in the victims of urban degradation are the riparian zone and vegetative buffers. Thinning or removal of indigenous vegetation along urban waters removes the beneficial functions associated with these natural features.

Roux, Kempster, Kleynhans and Vliet (1997) indicate that the assimilative capacity of the environment may undergo change where the rate of contaminant addition to the environment is increased. This occurrence holds true for freshwater resources, where the natural self-purification ability of these systems are disrupted by pollution (Kupchella and Hyland, 1993). Urban rivers persistently bear the brunt of high pollution loads which encumber this inherent cleansing function.

2.5. Socio-Economic Attributes

At the core of the definition of ‘urban’ is a statistical concept of demographic processes. Humans inhabiting an urban catchment are almost inescapably influenced by the local watercourses. The extent to which they are affected however varies.

Some urban dwellers are more dependent on water resources than others. This is especially evident in areas where services lack, such as informal settlements. Here water may be directly taken from the rivers for a variety of uses, for example cooking, cleaning and washing. Rivers flowing through such areas are also often used as easy means of disposing of waste.

In serviced areas, urban rivers are frequently used only for recreational (active and passive) purposes. The manner in which these waterways are enjoyed greatly pertain to the degree of degradation. Where pollution prevents ingestion or even contact, urban watercourses are mostly enjoyed from an aesthetic perspective. The amenity value of bankside recreation is however dependant on the absence of odour, litter and algae scums (Petts, Heathcote and Martin, 2002).

In many countries rivers hold religious connotations. For example, in South Africa some religious groups use urban rivers to perform ceremonies, such as baptisms. Urban rivers also grant opportunities for educational programmes. Key localities along some urban rivers are often assigned as conservation areas (e.g. bird sanctuaries) to allow for both environmental preservation and community gratification.

Pathogens, primarily introduced to urban watercourses by faecal contamination, pose health risks to humans. In addition, risk of injury is also posed by watercourses where erosion has left steep banks.

According to Hanley, Shogren and White (1997), the natural environment and the economy are interlinked in four ways, with the environment supplying material and energy resource inputs, waste assimilative capacity, amenity and global life support services to the economic process. A few examples of the premise that urban water resources hold economic implications are as follows:

- Polluted water increases expenditure on purification;
- Rising floodlines pose serious threats to structures located within the urban river's floodplain;
- Depending on their level of degradation, urban watercourses elevate property values;
- Urban rivers are costly to rehabilitate; and
- Water transfer schemes are coupled with high costs, largely associated with infrastructure.

C. WATER QUALITY AspECTS

1. DEFINING WATER QUALITY IN AN URBAN RIVER CONTEXT

1.1. Introduction

The state of an urban river can easily be ascertained by inspecting its water quality. It is that attribute of the watercourse that divulges, amongst others, its suitability for use, ability to sustain life, and overall detachment from a more natural state.

The chemical composition of surface water is dependant on a multitude of factors, such as the location, climate and make-up (e.g. geology, geography) of the waterbody in question. The nature and concentration of chemical elements and compounds in a freshwater system are subject to change by various types of natural process (i.e. physical, chemical, hydrological and biological), and the most important of these processes and the water bodies they affect are listed in **Table C.1**.

Naturally occurring substances (e.g. inorganic and organic matter, dissolved nutrients, trace metals, dissolved gases) grant surface water its inherent quality, in the absence of human influence. Urban rivers are however by definition not pristine, and constitute many substances from artificial origin.

Changes to water quality are often as a result of pollution. Humans are not always to blame for contamination of urban rivers as natural sources, such as floods and fires, also contribute. Even natural chemical species are considered contaminants when their quantities exceed their normal background concentrations (Schmits, 1996). However, the deterioration of the quality of urban freshwater resources can be largely ascribed to anthropogenic activities within the catchment.

Urban freshwater pollution is the introduction of a substance into the aquatic system, with subsequent detrimental effects to the receiving environment. The nature of a contaminant, and its concomitant capacity to impact on the aquatic environment, is influenced by the chemistry of the receiving waters.

<u>Table C.1:</u> Key processes affecting water quality (Bartram and Ballance, 1996)

Process type	Major process within water body	Water body
Hydrological	Dilution	All water bodies
	Evaporation	Surface waters
	Percolation and leaching	Groundwaters
	Suspension and settling	Surface waters
Physical	Gas exchange with atmosphere	Mostly rivers and lakes
	Volatilisation	Mostly rivers and lakes
	Adsorption/desorption	All water bodies
	Heating and cooling	Mostly rivers and lakes
	Diffusion	
Chemical	Photodegradation	
	Acid base reactions	All water bodies
	Redox reactions	All water bodies
	Dissolution of particles	All water bodies
	Precipitation of minerals	All water bodies
	Ionic exchange1	Groundwaters
Biological	Primary production	Surface waters
	Microbial die-off and growth	All water bodies
	Decomposition of organic matter	Mostly rivers and lakes
	Bioaccumulation	Mostly rivers and lakes
	Biomagnification	Mostly rivers and lakes

Pollution renders watercourses unfit for usage. Water use no longer just applies to human-related activities. The South African National Water Act (Act 36 of 1998) acknowledges the aquatic ecosystem as a legitimate water user, and takes into consideration the needs of this user in the form of the Reserve. The Reserve is defined as the water needed to protect basic human and environmental needs (DWAF, 1999b).

1.2. Urban Influence

Urban influence on water quality is best appreciated when examining water pollution. Such an investigation requires an understanding of the movement of the pollutant, by identifying the source(s), the pathways, and the end point of the pollutant (Schmits, 1996).

Pollution sources are classified under point and non-point sources. Point sources include distinguishable pollution sources that discharge directly into channels (e.g. industrial effluent), whereas non-point/diffuse sources reach the river channel by a variety of routes (i.e. runoff). The pollution source affects the pathway by which the pollutant comes into contact with the urban watercourse.

In the context of this project, the receiving environments (i.e. end points) of the urban-related contaminants are the local waterbodies. The water systems transport pollutants downstream, where the end-destination depends on the ambient conditions and the character of the pollutant.

Watercourses contain an assimilative capacity, which allows these systems to undergo natural purification. The assimilative capacity of the receiving water is defined as the capacity of a waterbody to assimilate, through processes such as dilution, dispersion, and chemical and biological degradation, waste disposal to a waterbody without water quality changing to the extent that the "fitness for use" of the water or health of the natural aquatic environment is impaired (Roux *et al.*, 1999). This self-purification ability of a watercourse is however not infinite, where its assimilative capacity may be diminished and eventually exhausted by pollution accumulation (Toman and Withagen, 2000).

CASE STUDY

The Upper Jukskei River is exposed to a diversity of pollutants associated with urbanisation, with anthropogenic influences as the main driver for the current degraded state of the watercourse. Refer to **Figure C.1** for a map of the Upper Jukskei River and its tributaries.

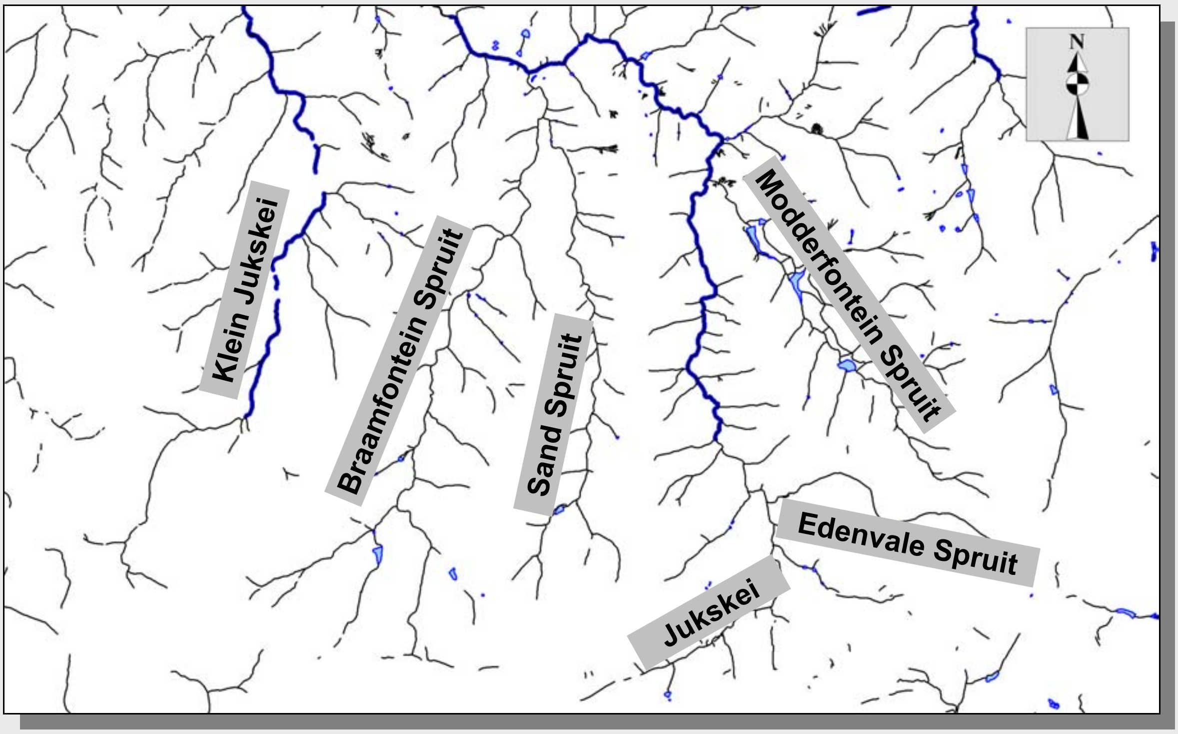


Figure C.1: Map of Upper Jukskei River and its tributaries

Significant point sources of pollution in the Upper Jukskei include the Northern Sewage Treatment Works, AECI and Kelvin Power Station.

Non-point pollution sources are prevalent in the catchment. Residential land use constitutes the majority of the catchment, with informal residential areas primarily encountered in Alexandra. Sediment, organic waste, litter, fuels, wastewater and sewage present some of the pollutants originating from these areas, which are transported to the Jukskei via runoff. Industrial areas are also a source of a variety of contaminants, which end up in the river where suitable control measures (e.g. housekeeping, waste control) are lacking.

CASE STUDY (continued)

Arguably, the most severe pollutant in the Jukskei River is faecal matter, with consequential problems including eutrophication. Sewage pollution is already encountered in the headwaters, caused by overburdened and old sewage infrastructure in Johannesburg CBD. This problem is exacerbated by the fact that the stormwater and sewer systems are superimposed, with the sewer manhole positioned below the stormwater drainage line. As a result of the upstream sewage pollution, the Bruma Lake is an exceedingly trophic impoundment due to its high organic content, with the occurrence of foul odours, discolouration and dense algal growth.

Further downstream at Alexandra, sewage is disposed off into the Jukskei as a result of a shortage or improper use of sanitation facilities.

Apart from chemical and physical water pollution associated with diffuse and point sources, biological pollution plays an important role in the degradation of the Upper Jukskei. This type of impact has two perspectives. The first of these is the addition of disease-causing agents (i.e. pathogens) and parasites to the aquatic environment, caused by sewage pollution. The second perspective is the introduction of non-indigenous species, specifically in the riparian zone, where there occurs a loss of beneficial functions associated with the natural riparian vegetation (e.g. purification of runoff).

Further mention of pollution in the Upper Jukskei catchment is made in the case study boxes in **Section C 1.3** below.

1.3. Effects of Urban Land Use on Water Quality

According to Jessel and Jacobs (2005), the type and intensity of land use in river catchments has a significant impact on diffuse pollution. This section discusses the impacts of land use types (i.e. agriculture, industry, mining, commercial, residential and recreational) on the water quality of urban watercourses. Since most water quality problems have a land use origin, the exploration of land use practices will assist the understanding of urban–related water quality issues.

Table C.2 presents more common pollutants and their sources (land use types), as well as the water quality (and related) impacts.

Table C.2: Common pollutants, their sources and the associated water quality and related impacts (Murdoch, Cheo and O'Laughlin, 1996)

POLLUTANT	SOURCES	WATER QUALITY AND RELATED IMPACTS
Sediment	▪ Agriculture ▪ Crops & grazing ▪ Forestry ▪ Urban runoff ▪ Construction ▪ Mining	▪ Decreases water clarity and light transmission through water, which: – Causes a decrease in aquatic plant production – Obscures sources of food, habitats, refuges, and nesting sites of fish – Interferes with fish behaviours which rely on sight (e.g. mating) ▪ Adversely affects respiration of fish by clogging gills ▪ Fills gravel spaces in stream bottoms, smothering fish eggs and juveniles ▪ Inhibits feeding and respiration of macroinvertebrates, an important component of fish diets ▪ Decreases dissolved oxygen concentration ▪ Acts as a substrate for organic pollutants, including pesticides ▪ Decreases recreational, commercial and aesthetic values of streams ▪ Decreases quality of drinking water
Pesticides Herbicides	▪ Agriculture ▪ Forestry ▪ Urban runoff	▪ Kill aquatic organisms that are not targets ▪ Adversely affect reproduction, growth, respiration, and development in aquatic organisms ▪ Reduce food supply and destroy habitat of aquatic species ▪ Accumulate in tissues of plants, macroinvertebrates and fish ▪ Some are carcinogenic (cause cancer), mutagenic (induce changes in genetic materials-(DNA)), and/or teratogenic (cause birth defects) ▪ Create health hazards for humans consuming contaminated fish or drinking water ▪ Lower organisms' resistance and increase susceptibility to diseases and environmental stress ▪ Decreases photosynthesis in aquatic plants ▪ Reduces recreational and commercial activities
Polychlorinated Biphenyls (PCBs)	▪ Urban runoff ▪ Landfills	▪ Accumulate in tissues of plants, microinvertebrates and fish ▪ Toxic to aquatic life ▪ Adhere to sediments; persist in environment longer than most chlorinated compounds

Table C.2: (continued)

POLLUTANT	SOURCES	WATER QUALITY AND RELATED IMPACTS
Petroleum Hydrocarbons	Urban runoff	▪ Water soluble components can be toxic to aquatic life ▪ Portions may adhere to organic matter and be deposited in sediment ▪ May adversely affect biological functions
Pathogens and faecal bacteria	▪ Agriculture ▪ Forestry ▪ Urban runoff	▪ Create human health hazard ▪ Increase costs of treating drinking water ▪ Reduce recreational value
Nutrients (phosphorus, nitrogen)	▪ Agriculture ▪ Forestry ▪ Urban runoff ▪ Construction	▪ Overstimulate growth of algae and aquatic plants, which later, through their decay, cause: – Reduced oxygen levels that adversely affect fish and other aquatic organisms – Turbid conditions that eliminate habitat and food sources for aquatic organisms – Reduced recreational opportunities – Reduced water quality and increased costs of treatment – A decline in sensitive fish species and an over-abundance of nutrient-tolerant fish species, decreasing overall diversity of the fish community – Premature aging of streams, lakes, & estuaries ▪ High concentrations of nitrates can cause health problems in infants
Metals	▪ Urban runoff ▪ Industrial runoff ▪ Mining ▪ Automobile use	▪ Adversely affect reproduction rates and life spans of aquatic organisms ▪ Adversely disrupt food chain in aquatic environments ▪ Accumulate in bottom sediments, posing risks to bottom feeding organisms ▪ Accumulate in tissues of plants, macroinvertebrates, and fish ▪ Reduce water quality
Radionuclides	▪ Mining and ore processing ▪ Nuclear power-plant ▪ Fuel and wastes ▪ Commercial/ industry	▪ Release radioactive substances into streams ▪ Some are toxic, carcinogenic (cancer causing) and mutagenic (induce change in genetic materials-DNA) ▪ Some break down into “daughter” products, such as radium and lead, which are toxic and carcinogenic to aquatic organisms ▪ Some persist in the environment for thousands of years and continue to emit radiation ▪ Accumulate in tissues, bones and organs where they can continue to emit radiation

Table C.2: **(continued)**

POLLUTANT	SOURCES	WATER QUALITY AND RELATED IMPACTS
Sulfates	▪ Mining ▪ Industrial runoff	▪ Lower pH (increase acidity) in streams which stresses aquatic life and leaches toxic metals out of sediment and rocks ▪ High acidity and concentrations of heavy metals can be fatal to aquatic organisms, may eliminate entire aquatic communities
Salts	▪ Agriculture ▪ Mining ▪ Urban runoff	▪ Eliminate salt intolerant species, decreasing diversity ▪ Can fluctuate in concentration, adversely affecting both tolerant and intolerant species ▪ Impact stream habitats and plants which are food sources for macroinvertebrates ▪ Reduce crop yield ▪ Decrease quality of drinking water ▪ Reduce recreation values through high salinity levels and high evaporation rates

CASE STUDY

The land use types in the Upper Jukskei Catchment are indicated in **Figure C.2** below.

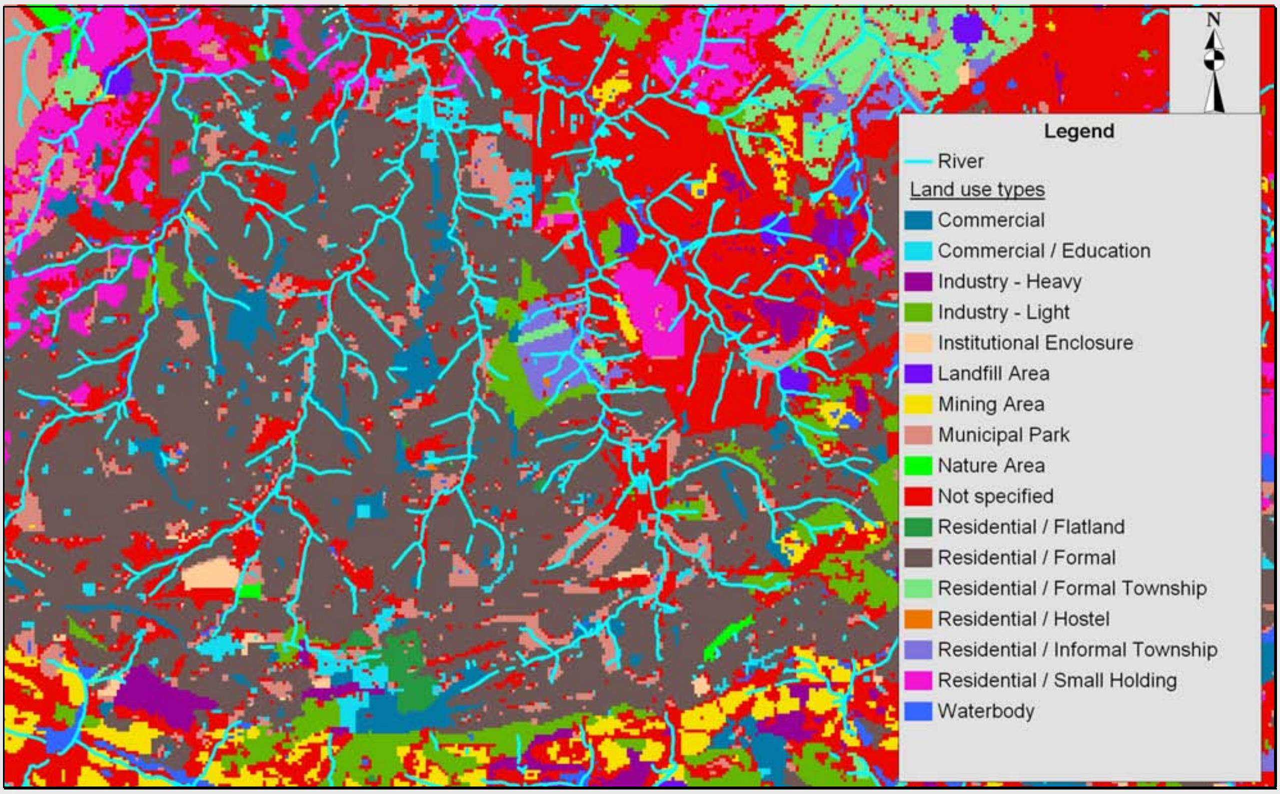


Figure C.2: **Land use types in the Upper Jukskei Catchment**

1.3.1. Agriculture

Urban agriculture in cities or towns in South Africa are mostly performed on a subsistence level, with limited commercial enterprises. Subsistence farming is often undertaken along urban watercourses, as these areas grant open space and easy access to free water for irrigation purposes.

The adverse effects from this practice to urban watercourses are initiated as early as land preparation, where natural vegetation is removed to prepare farming land and the beneficial functions of vegetation (e.g. stormwater retention and purification, erosion prevention) are lost.

Depending on the type and method of farming, the pollutants include fertilisers, pesticides and sediment. Where livestock is involved, the impacts to the aquatic environment may be overgrazing, damage to riparian zones, and eutrophication through the conveyance of their excrement to the nearby waters.

The activities associated with urban agriculture serve primarily as non-point pollution sources, where contamination of freshwater systems occurs through drainage water.

Refer to **Section E** on **Urban Agriculture** for more in-depth reading on this matter.

CASE STUDY
In Alexandra only small patches of land are utilised for urban agricultural purposes. Problems surrounding the keeping of livestock in Alexandra include animal waste and destruction of vegetation (especially by goats).

CASE STUDY (continued)

At Leeuwkop Prison water is abstracted from the Jukskei River and the Sand Spruit for irrigation of mainly vegetables, corn and grazing land. Pesticides and fertilizers, used as part of the farming practices, contaminate runoff which reduces water quality of the receiving freshwater system. In addition, overland drainage from the pigpen leads to organic enrichment of the Jukskei River.

Another noteworthy agricultural area in the Upper Jukskei is located along one of its tributaries, namely the Modderfontein Spruit. The AECI property, in Modderfontein, historically irrigated their agricultural land with factory waste, the primary component of this being nitrates.

1.3.2. Industry

Frequent causes of industrial contamination of watercourses include illicit practices or inadequate housekeeping, poor storage practices, poor waste management practices, and insufficient stormwater management practices. Industry is a combination of a point and non-point source of pollution, and results in the release of raw materials, by-products and industrial end products into urban rivers.

The toxicity of the contaminants depends on the type of industry and condition of the receiving aquatic environment. According to Moss (1989), discharged industrial substances of particular concern are heavy metals (e.g. lead, mercury, cadmium, copper, chromium, zinc) and chlorinated hydrocarbons (e.g. polychlorinated biphenyls). Another environmental hazard is the industrial release of sulphur dioxide to the atmosphere, resulting in the acidification of rain.

Refer to the **Sections G** and **H** on **Industry** and **Waste** respectively for more in-depth readings on this topic.

CASE STUDY

Noteworthy industrial areas in the Upper Jukskei Catchment include:

- Doornfontein;
- New Doornfontein;
- Troyeville;
- Kew;
- Marlboro;
- Eastleigh light industrial area;
- Isando,
- Modderfontein.

Effluent from the Northern Sewage Treatment Works may result in elevated NH_4, PO_4 and E.coli levels.

Kelvin Power Station and the AECI factory serve as point and diffuse sources of industrial pollution of the Modderfontein Spruit. Typical effluent from AECI contains NH_4, NO3, Na, SO4, TOS and F, and for Kelvin Power Station it contains suspended particles (DWAF, 1992).

1.3.3. Mining

Mining activities introduce a series of stressors to the aquatic environment. The most notorious impact associated with mining is the occurrence of Acid Mine Drainage (AMD), i.e. the process whereby pyrite (FeS_2) is oxidised to create sulphuric acid. Leaching of metals (e.g. arsenic, nickel, copper, zinc and aluminium) is further accelerated through low pH conditions induced by AMD.

Surface drainage delivers AMD by-products to the nearby river, causing acidic conditions and an accruement of metal ion concentrations and suspended solids. Rösner, Boer, Reyneke, Aucamp, and Vermaak. (2001) state that acid drainage originating from gold residue material in South Africa generally contains large quantities of salts, considerable concentrations of toxic heavy metals and trace metals such as copper, arsenic, and cyanide, as well as radionuclides.

Mining further leads to the deposition of substantial quantities of silt in the river systems, from disturbed areas.

A significant risk to the surface water resources from mining is the discharge of excess underground water from operating and defunct mining operations. Mining-related contaminants reach urban rivers primarily though overland flow, and thus serves as a diffuse pollution source.

CASE STUDY

Johannesburg is separated by the mining belt into two distinct basins, namely the Jukskei (draining northwards) and Klipspruit (draining southwards) catchments. Mining areas occur mainly in the Klipspruit catchment.

According to DWAF (1992), it is however believed that mine dumps also occurred in Bedfordview, which have subsequently been reworked and the land has been develop.

Tailings dams are situated at AECI, and may potentially lead to the pollution of the Modderfontein Spruit where fluoride, chloride and sulphate are present in the stormwater runoff.

1.3.4. Commercial

Commercial land use includes those areas used predominantly for the sale of products and services. Commercial areas include central business districts (CBDs), shopping centres, commercial strip developments, resorts, etc.

Commercial activities are non-point pollution sources. Causes of pollution from commercial activities are often associated with the failure to practice good housekeeping and improper waste and stormwater management.

CASE STUDY

The main commercial areas in the Upper Jukskei Catchment include CBDs (e.g. Johannesburg, Randburg, Sandton) and shopping centres (e.g. Sandton, Cresta, Fourways, Rosebank, Northgate).

Numerous car washes in the Upper Jukskei Catchment create effluent that contains soap water, which result in water pollution where stormwater management is lacking.

Formal and informal commercial activities in Alexandra, which can act as diffuse sources include the following:

- Taverns and shebeens;
- Hawkers;
- Car washes;
- Mechanics; and
- Butcheries.

1.3.5. Residential

In more affluent areas, use of detergents for washing (e.g. cars, driveways) add pollutants such as phosphate to nearby rivers (via overland drainage). The soap used is viewed as a man-made surfactant (surface-active agents). They reduce the rate of re-aeration of water and thus reduce the amount of oxygen available to the biota (Dallas, 1995). The effects of non-biodegradable detergents are much more severe than with biodegradable detergents.

Watering of gardens generates runoff, which could transport sediment, debris and organic waste to the receiving watercourses.

Improper discarding of wastewater in informal areas reduces water quality. Lack of suitable services and uninformed habitants of these areas present the primary causes of domestic-related pollution.

CASE STUDY
Bulk water is supplied to Gauteng by Rand Water, where water is obtained from the Vaal River system. Johannesburg Water serves as the Water Service Authority, and supplies potable water to domestic water users in the Upper Jukskei Catchment. There is no formal abstraction of water from the Jukskei River for domestic needs. In the Alexandra area, water is known to be used directly from the Jukskei for cooking and cleaning purposes. In various areas along the Upper Jukskei the cleaning of clothes and bathing in the river occurs. Influence to water quality from residential land use is mainly in the form of diffuse pollution, where stormwater drainage conveys substances such as organic matter, oils, fuels and detergents to the Jukskei. With formal residential areas constituting the majority of the land use in the catchment, pollution from this sector is considered as significant.

1.3.6. Recreational

The utilisation of urban rivers for recreational activities is greatly dependant on the water quality. The level of pollution dictates the type of recreational enjoyment associated with urban waters. Risk to human health exists in those freshwater systems where toxic chemicals and disease-causing agents are present. As a result of the often degraded state of urban waters, recreational use of these watercourses is mostly restricted to passive (e.g. picnicking, meditation) and active (e.g. jogging, games) recreation.

Some ways in which recreational use affects water quality include:

1. In the case of recreational activities involving body contact, such as swimming, pathogens could be introduced into water through direct contact.
2. Instream activities may increase bacterial concentrations by creating turbulence that disturbs the bottom sediment, which may contain higher concentrations of bacteria than surface water;
3. The turbidity of water can be increased by the erosion of the banks at popular crossing points;
4. Improper waste disposal may lead to the occurrence of refuse in the watercourse; and
5. Golf courses cause pollution from chemical fertilizers, herbicides and pesticides used for turf management, and the courses add to sediment loads.

The use of and adverse effects from recreational use on rivers is discussed in more detail in the **Section D** on **Socio-Economic Aspects**.

CASE STUDY
Various dams were built in the Upper Jukskei to allow for recreational use of this watercourse. Examples of such impoundments include Bruma Lake, Westdene Dam, Zoo Lake and Emmarentia Dam. There is an ongoing struggle with high pollutant levels in the Bruma Lake, originating from upstream sources, which detracts from the aesthetic value of this waterbody. Many golf courses are located in the catchment (e.g. Huddle Park, Glendower, Houghton, Wanderers, Modderfontein, River Club, Royal Johannesburg and Kensington), where the Jukskei and its tributaries are used for scenic value, irrigation of grass, and water hazards during play.

CASE STUDY (continued)
Walking trails are situated along the Upper Jukskei and its tributaries. Examples of trails include the Klein Jukskei Nature Trail, Outspan Trail and Jukskei River Trail.

1.4. Managing Water Quality of Urban Rivers

1.4.1. Water Quality Appraisal

When assessing the water quality of an urban watercourse, the following should be considered:

- Objectives of water quality appraisal;
- Assignment of duties;
- Monitoring methodology;
- Monitoring programme; and
- Assessment of water quality results.

1) Objectives of Water Quality Appraisal:

Some of the main imperatives for assessing water quality of urban rivers include:

1. Chapter 14 of the National Water Act (No. 36 of 1998) requires the establishment of a national monitoring system on water resources for the collection of appropriate information, *inter alia,* on the quantity and quality of water resources and the health of aquatic ecosystems.
2. One of the most important reasons for identifying the water quality condition is to determine whether the needs of the water users are being met.
3. By determining the water quality of urban waters on an on-going basis, at strategic points, pollution incidences can be detected. This grants authorities the opportunity to intervene and undertake, or demand from the polluter, remedial actions.
4. In the instance of a licensed water use, water quality assessments may be imposed upon the licence holder by DWAF. The objective would thus be to satisfy the requirements of the licence conditions.

5. Communicating the state of urban water to the inhabitants of the catchment is a valuable method in maintaining interest from the public and private sectors, and it instils river stewardship.

CASE STUDY
The water quality monitoring programme undertaken by the City of Johannesburg on the Jukskei River intends to identify areas for intervention, to enhance the overall water quality of the system. In this endeavour, the City collaborates with stakeholders such as DWAF, the Jukskei River Forum, other municipalities and public and private interest groups.

2) Assignment of Duties:

Duties, in this context, refer to the responsibility of monitoring and assessing water quality of urban rivers. According to DWAF (2004a), "monitoring" describes three interrelated functions, which are data acquisition, data management and storage, and information dissemination. "Assessment" is the follow-on activity to monitoring, where meaningful deductions are made about the water quality data (refer to section on assessment of water quality results).

As far as the responsibilities for law enforcement are concerned, DWAF is the custodian of our country's water resources. Various DWAF Directorates, in cooperation with the nine DWAF Regional Offices, are charged with the governance of aspects of water quality in South Africa. The municipalities are also charged with monitoring and assessing water quality of the waterways located within their boundaries of jurisdiction.

The chief responsibility for monitoring compliance with licence conditions is assigned to the water users. For example, where industries discharge effluent into water bodies, those parties are responsible for monitoring the quality of their effluent. DWAF, as the licencing authority, periodically audits the monitoring results submitted by the water users.

The public has the right to notify authorities of pollution events. DWAF encourages civic involvement, and provides contact numbers for the Head Office and Regional Offices to report pollution offenders.

CASE STUDY

Compliance monitoring programmes of significant point source pollution (in terms of licence conditions) in the Upper Jukskei include the following:

- Johannesburg Water's compliance monitoring at Northern Sewage Treatment Works;
- Compliance monitoring at AECI; and
- Compliance monitoring at Kelvin.

3) Monitoring Methodology:

Water quality monitoring techniques provide means with which we can detect and characterise impacts to urban freshwater systems. According to Bartram and Ballance (1996), the complete assessment of the quality of the aquatic environment requires that water quality, biological life, particulate matter and the physical characteristics of the water body be investigated and evaluated. This can be achieved through:

- **Chemical** analyses of water, where quality may be expressed in terms of the concentration and state (dissolved or particulate) of some or all of the material (organic and inorganic) present in the water;
- **Biological** tests, such as toxicity tests and measurements of enzyme activities;
- **Descriptions of aquatic organisms**, including their occurrence, density, biomass, physiology and diversity (from which, for example, a biotic index may be developed or microbiological characteristics determined); and
- **Physical** measurements of water temperature, pH, conductivity, light penetration, particle size of suspended and deposited material, dimensions of the water body, flow velocity, hydrological balance, etc.

In the past, most pollution monitoring programs trusted chemical-physical parameters (e.g. dissolved oxygen, pH, conductivity, turbidity, etc.) to evaluate the condition of a water body. It was however realised that these methods were insufficient to assess the health of an aquatic system (Worf, 1980; Hellawell, 1986; DWAF, 1997). Chemical monitoring covers only a fraction of the possible toxins that may be present in water and the chemical analysis process takes a relatively long time in comparison with the reaction time of organisms. Further, chemical monitoring doesn't take into account many man-induced disturbances (e.g., flow alterations), nor short-term pollution-induced stresses. Conveniently, aquatic organisms serve as integrators of their total environment, and their response to complex sets of environmental conditions are used as monitors of water quality (Worf, 1980).

It is thus best to recruit all three monitoring types (i.e. chemical, physical and biological) when examining the water quality of urban watercourses.

As far as chemical and physical monitoring is concerned, analyses of samples are performed at accredited laboratories. The water quality parameters that are tested for depends on the types of pollution sources in the catchment, the variables of concern and the objectives of the monitoring programme. Handheld apparatus may also be used in the field to test for water quality constituents such as pH, conductivity, dissolved oxygen and temperature.

CASE STUDY

The City of Johannesburg water quality monitoring programme tests largely for chemical, physical and bacteriological parameters. Biomonitoring is performed at selected localities.

Likewise, AECI performs chemical, physical and biological water quality monitoring.

As part of the River Health Programme (RHP), the Gauteng Department of Agriculture, Conservation and Environment (GDACE) monitors the ecological status of the Jukskei River at two sites in the upper catchment (Muller, 2004).

Biomonitoring of the Upper Jukskei Catchment involves the appraisal of the aquatic macroinvertebrate communities, through the use of the South African Scoring System (SASS) biotic index, as well as the instream and riparian habitat.

4) Monitoring Programme:

Vital in the design of the monitoring programme is the location of the monitoring sites, selection of water quality variables to be tested for and the frequency and timing of sampling.

Choosing the correct locality may determine the success of the monitoring exercise in terms of identifying pollution events and sources, and allowing for continued and unproblematic sampling (i.e. accessibility). Special consideration should also be given to historical monitoring sites as past data can be used.

Important factors that influence the selection of water quality variables that are to be tested for depend on the pollution type (e.g. effluent composition), sensitivity of the water resource, ambient water quality conditions of the urban river, downstream water users, and license requirements.

Sampling frequency is not just a question of diligence, where the severity of pollution, types of parameters to be tested, availability of resources (human and financial), legal obligations (e.g. compliance with licence conditions) and other aspects play important roles.

Data should be collected during stable, unscoured, flow conditions. Ideally streams should be sampled no earlier than two weeks after a significant scouring event. Sampling during extreme weather conditions (i.e. significant drought or heavy rains) should be avoided.

CASE STUDY
The Jukskei River water quality monitoring programme by the City of Johannesburg was initiated in October 1993. Monitoring is performed on a fortnightly basis at strategic sampling points (refer to **Figure C.3**) in the catchment. CYDNA Laboratory is responsible for analysing the samples (Rimmer, 2002).

CASE STUDY (continued)

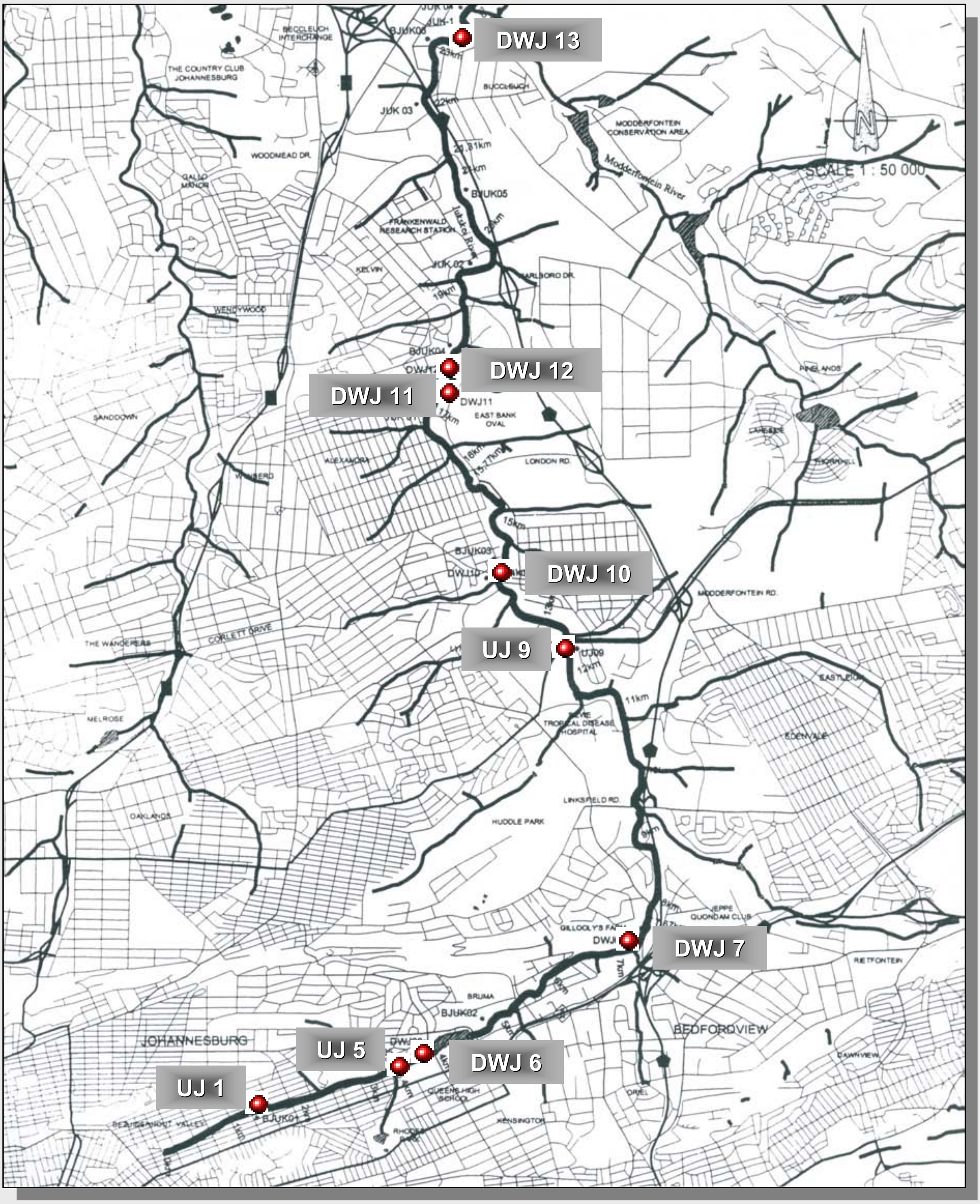


Figure C.3: **City of Johannesburg water quality monitoring points in the Jukskei River**

CASE STUDY (continued)

AECI undertakes water quality monitoring of the Jukskei River upstream and downstream of the confluence of the Jukskei River and the Modderfontein Spruit (van Dongen, 2002).

5) Assessment of Water Quality Results:

Once data on an urban water resource is available, an assessment is required to interpret the results in a meaningful manner.

According to Heath (1993), subsequent to the ratification of the old Water Act of 1956 (Act 54 of 1956) pollution control of the country's water resources was primarily performed by applying a uniform effluent standard. Following improvements, a resource-based approach was adopted, where the water resources where adjudicated as fit for a certain use, according to water quality requirements of recognised water users (i.e. water quality objectives). The requirements of the different water users are summarised in the South African Water Quality Guidelines, prepared by DWAF. These guidelines stipulate the requisite ranges of water quality variables that are necessary to render water fit for the five user groups, namely agriculture, industry, domestic, recreation, and aquatic ecology.

Resource quality objectives (RQOs) are the primary management objectives against which monitoring data should be assessed. RQOs are defined in the integrated Resource Directed Measures (RDM) manual (DWAF, 1999b) as "a numerical or descriptive statement of the conditions which should be met in the receiving water resource, in order to ensure that the water resource is protected." RQOs present defined objectives for flow, quality, biota and habitat.

CASE STUDY

The City of Johannesburg Development Planning, Transportation and Environment interprets the variables tested for in the water quality monitoring programme and calculates an index which enables each monitoring point to be placed in a class corresponding to the index, where each class is accompanied by a representative colour and description (Eshen, 2002). A summary report presenting the classes for the monitoring points in the Jukskei River catchment is prepared periodically by this department.

DWAF (1999a) provides Water Quality Objectives for the Jukskei River catchment. Comparison of past water quality monitoring results with these objectives consistently highlight nutrients, faecal coliforms, turbidity and ammonia as variables of concern in the Upper Jukskei.

1.4.2. Management

Following the appraisal of the water quality, management measures are needed to address the variables of concern.

Pegram, Gorgens and Otterman (1997) provide the type of assessment and management decisions required at each stage of water quality assessment, as indicated in **Table C.3**. According to **Table C.3** the assessment of water quality stretches further than only evaluating data and identifying problematic constituents, with various levels of assessment playing particular roles in the management of a catchment's water quality. Note that the "Situation Analysis" component of this process is geared towards water quality appraisal, which is covered under **Section C 1.4.1**.

<u>Table C.3:</u> **Assessment actions supporting management decisions at different levels of assessment (Pegram *et al.*, 1997)**

Management Phase	Level of Assessment	Assessment Action ➔ Management decision
	Screening/ scoping	Preliminary overview of the existence and extent of a problem ➔ The water quality issues to manage
Situation Analysis	Evaluation	Detailed investigation of the cause-and-effect relationship ➔ Key areas and constituents of concern
	Prioritisation	Rank problems & causes in terms of severity and manageability ➔ Priority sources and/or waterbodies and management strategies
Planning	Selection	Design and estimate the cost-effectiveness of possible actions ➔ Appropriate actions to achieve the specified strategies
	Operation	Estimate the impacts of "real-time" actions ➔ Ongoing operational decisions
Implementation	Auditing	Monitor the degree to which conditions are meeting objectives ➔ Reassessment, replanning or further implementation

From a regulatory perspective, DWAF has adopted two main approaches for the management of water resources, namely Resource Directed Measures (RDM) and Source Directed Controls (SDC). According to DWAF (2004b), RDM focus on the quality of the resource itself, specifically on the resource as an ecosystem rather than a commodity. RDM is based on developing a classification system, determining RQOs and setting the Reserve.

SDCs focus on managing the quality and quantity of water entering a resource after use, to control the impact that it might have on that resource. SDCs are primarily designed to control water use activities at the source of impact, through tools such as standards, regulations, water use authorisations and economic instruments.

According to DWAF (2003), other water quality management options may include the following:

1. Statutory Controls on water use, including stricter authorisation conditions (through area-specific general authorisations or licences), or compulsory licensing of applicable water quality-based water users;

2. Waste Discharge Charges used as an economic incentive to reduce loads to the required levels, as well as funding of direct interventions to implement technologies and practices to control loads from particular sources;
3. Non-Statutory Options, especially cooperative governance and capacity-building to:
   – Enhance the effectiveness of land use and infrastructure management that impacts on water quality;
   – Alter water users' (in the wider definition) and land users' behaviour to focus on their possible contribution to mitigation of impacts;
4. In-Stream Water Quality Management through remediation of the water resource, reservoir/river system operation and/or ensuring adequate water quantity allocation to streamflow for dilution and assimilation of loads; and
5. Water Use Water Quality Management, either as Demand Management approaches relevant to Water Quality Management, or as pre-use treatment options; or as a migration to other water use types.

D. SOCIO–ECONOMIC ASPECTS

The efficient and sustainable management of water resources calls for the consideration of the biophysical, economic and social aspects of a system. The strong linkage between humans and the natural environment within which they exist underscores the significance of the socio-economic backdrop of urban watercourses. As an appreciation of this relationship, the topic of **Section D** is the socio-economic context of urban waterways.

1. DEFINING THE SOCIO-ECONOMIC CONTEXT OF URBAN RIVERS

1.1. Introduction

Dederen *et al.* (2001), notes that sociological input in the study of a river is necessary because "people living in a particular area posses indigenous knowledge, capacities and aspirations that are relevant to the management of such resources as well as of its cultural, religious and recreational values".

The word "society" (and hence the prefix "socio") applies in its broadest sense to all human activity. Social impacts refer to changes in community cohesion, vitality, confidence and the demographic make up of local and regional communities (Independent Advisory Committee on Socio-Economic Analysis, 1998). Due to population increase socio-economic issues include some of the major problems facing the world.

Economic indicators are a clear reflection of the standard of living among communities. As population numbers drastically rise, the quality of life and availability of resources diminish. According to the Independent Advisory Committee on Socio-Economic Analysis (1998), economic effects refer to changes in well-being, regardless of whether these changes are reflected in monetary flows.

Socio economic impacts include change that occur in the following:

- People’s way of life (how they live, work and interact with each other);
- Cultural traditions (shared beliefs, customs and values);
- The community (it’s cohesion, stability, character services and facilities); and
- The standard and quality of life (level of income, ranges of choice in consumption and the quality and quantity of community infrastructure).

A “healthy river” is widely accepted as socially desirable, and it is a reflection of the quality of life and the quality of “the city” (Petts *et al.*, 2002). However, the world’s rivers are in a crisis and “more than one-half of the world’s major rivers are being seriously depleted and polluted”, thus threatening the health and livelihood of people who depend on them for various uses (City of Johannesburg, 2002).

The discussions to follow examine pertinent socio-economic uses of urban rivers, as well as the socio-economic issues with regard to urban waters.

CASE STUDY

The burdens present in the Upper Jukskei River catchment coincide with conditions faced by most urban rivers worldwide, and impacting factors such as floods, faecal contamination and litter have left the aquatic system in a poor state of health and severely degraded.

From a socio-economic perspective, the Upper Jukskei River passes different economic groups, as is evident in **Figures D.1** and **D.2**.

Figure D.1: An informal settlement along the Upper Jukskei River

Figure D.2: An affluent residential area along the Upper Jukskei River

1.2. Dense Settlements

In some parts of the world, and particularly dense and informal settlements, urban dwellers are reliant on urban watercourse for drinking purposes. A settlement can refer to any area of human habitation from single dwellings to high-rise blocks of flats (DWAF, 2001a).

South Africa's densely populated settlements are likely to occur near water resources that require a lower level of protection. The impacts of settlements on watercourses are site-specific, and pollution from settlements primarily relates to inadequate waste and sanitation services, which are normally underlain by social and institutional causes (DWAF, 2001a). Social causes stem from the misuse of the system, either through lack of awareness or occasionally the deliberate misuse of services. Institutional causes relate to service providers that fail to maintain or operate the services properly. Pollution from the densely populated areas is primarily non-point in nature (DWAF, 2001a).

Historically disadvantaged areas are poor and characterised by high rates of unemployment, poor service delivery, incidences of crime, low income and poor education (Grobicki, 2001). Rivers that traverse these areas are also used as a means of disposing of wastewater, in instances where these households are without waste services and sewage systems. In more developed areas blockages result in sewerage discharges, which pollute the watercourse(s) situated within the affected catchment.

Sewage pollution results in increased purification costs at water treatment plants. The environmental costs include impairment of vegetation and wildlife, water quality and aquatic biota (Murray Darling Basin Commission, 2001). Maksimovic and Tejada-Guibert (2001) specify the impacts of faecal contamination as deleterious effects to the physical surroundings, water quality, biological communities, ground water and public health.

Ventilated Improved Pit Latrines (VIPs) are often situated nearby watercourses with resultant release of wastewater into the river (Mokwalo, 2004).

Infections are generally contracted by drinking contaminated water, recreational exposures to contaminated water and the consumption of raw food exposed to polluted water (DWAF, 2001a).

Dense settlements are often associated with the clearing of vegetative groundcover to make way for dwelling units. The beneficial functions of vegetation, such as soil stabilisation, stormwater retention and runoff purification are lost. In addition, bare areas contribute to high silt loads in urban waters.

Densely populated settlements comprise mostly of impervious surfaces. The inability of rainwater to penetrate soil in these areas causes masses of runoff to drain rapidly to urban watercourses.

Case Study

DACEL (2001) estimates the population of Alexandra (located along the Upper Jukskei River) to be between 320 000 and 350 000 people, with a population density of 770 people per hectare. There are approximately 7,500 households situated along the riverbank and the tributaries, at very high densities with poor services. These informal areas are not connected to the formal waterborne sewerage system and are serviced by chemical toilets. These chemical toilets are placed on the periphery of the informal settlement (refer to **Figures D.3** and **D.4**) because of space constraints within the areas and because of the threat of crime, dwellers do not venture out in the night to use the facilities.

Where chemical toilets are not utilised, inhabitants of Alexandra make use of the bucket system and dispose of the contents of the buckets into the Jukskei River.

CASE STUDY (continued)

Figure D.3: **Chemical toilets in Alexandra, placed alongside the Jukskei River**

Figure D.4: **Chemical toilets in Alexandra, placed alongside the Jukskei River**

1.3. Religious Rituals

Water and the natural environment is integrated in African people's culture. There are narratives and myths about the dangers of the river that families tell their children. These stories are important in that they deter children from going into the river (City of Johannesburg, 2002).

Rivers are often used for spiritual healing. African traditional healers believe that they can communicate with the spirits that confers healing powers on them. Water is also said to cleanse the spirit and give blessing (www.ourplanet.com/imgrersn/83/jackson.html). Some religious groups use urban rivers to perform ceremonies such as baptisms, and sermons are frequently held alongside rivers.

The Zulu people acknowledge water spirits including the river snake (the 'snake of the water that gives life'). This belief system unites people, both the living and the dead, with the natural forces, the non-human spirits and the supreme deities. In some areas in KwaZulu-Natal it is believed that the heavenly princes, inkosazana has rest days where she needs to have the river to herself. Accordingly the use of the river on her day-lesuku leNkosazana (Mondays and Saturdays) is strictly prohibited (www.csir.co.za/rhp/state_of_rivers/state_of_umgeni_02/umgeni.html).

According to the State of the Rivers report: uMngeni River and neighbouring rivers and streams (www.csir.co.za/rhp/state_of_rivers/state_of_umgeni_02/umgeni.html) in the uMlazi River, river ceremonies are conducted several times a year by about 78% of the Salem community. These include:

- Umsenga - the reed dance where young girls cut reeds and take them to the inkosi's house as a gesture of honour;
- Unomkhubulwane (Goddess of Water) - seeds are thrown into the river to ask the Goddess for blessings and a good harvest; and
- Weddings - the bride will bath in the river prior to the wedding ceremony to remove evil sprits and bless the marriage.

A degraded river reduces the acceptability of the river for ceremonial purposes. Almost all of the people in Salem acknowledge that respect for the river and it's attributes for cultural and religious ceremonies are diminishing. Reeds are also a key symbol for the Zulu people, as they believe that their people emerged from a bed of reeds in ancient times.

CASE STUDY

The cultural and spiritual significance of the Jukskei River was highlighted during a school competition and Workshop on Sustainable Development carried out during the compilation of the Jukskei River Environmental Management Framework (City of Johannesburg, 2002). Learners acknowledged that sangomas use the Jukskei River to treat people. M. Enoch, a grade 7 pupil, believes that by "treating people in the river their disease would be washed into the river and will flow with the water" (City of Johannesburg, 2002).

Vomiting in the river was another common practice, highlighted by the workshop participants on sustainable development. Alexandra's inhabitants believe it to be a cultural practice and therefore not a source of pollution.

Learner's drawings depicted the existing "myths" about the Jukskei River. Learners choose to incorporate pictures of crocodiles, huge fishes with sharp teeth and snakes. This line of thought in relation to the river evidently, emanates from the stories that are being told by the elders. Stories and taboos created around the rivers are aimed to deter children from going into the river.

1.4. Public Health

A water-borne disease is defined as an illness that is transmitted through contaminated water. Disease-causing germs normally multiply in water, which is not properly managed and treated for consumption.

Polluted water poses severe threats to human health, which is often associated with the bacteriological contamination due to poor sanitation and hygiene. In developing countries the health impacts associated with the use of rivers as open sewers include vector borne diseases and bacterial infections (Maksimovic and Tejada-Guibert, 2001). Water related diseases are categorised in three classes, namely water-borne, water-washed and water based. Malaria and denude fever (spread by mosquitoes) are common diseases in developing countries as well as schistosomiasis, filariasis, cholera, meningitis, ear, eye and skin infection and hepatitis (Maksimovic and Tejada-Guibert, 2001).

Cholera is water-borne bacterial infection associated with a lack of good quality drinking water and sanitation service. KwaZulu-Natal reported 116 170 cholera epidemic cases during 2000 and 2001 (RHP, 2002). In 1996 it was found that there are approximately 43 000 deaths in South Africa due to diarrhoeal disease, with a further one in every 14 South Africans requiring treatment for diarrhoea every year. It is estimated that diarrhoea costs South Africa R 4 billion every year (City of Johannesburg, 2002). Diarrhoea is one of the top two causes of death of children under the age of five in South Africa and is also responsible for growth stunting in many children (SA Health Review, 1999).

Harmful contaminants from other sources within the urban area, such as industrial pollutants also contribute to the danger of ingestion of river water. Some of these contaminants target certain organs and may be carcinogenic, depending on the dosage and human condition.

In developed countries concerns regarding impacts of urban wastewater on public health are mostly related to restricted recreational use of the watercourses, contamination of fish and closure of harvesting areas. Pollution of drinking water is rare and isolated incidents are caused by equipment breakdowns or human errors.

CASE STUDY

Diarrhoeal disease is a health problem occurring frequently in Alexandra, primarily due to living conditions, as well as use of Jukskei River water for domestic purposes. The informal dwellings on the west bank of Alexandra are the worst affected by this illness, with higher density living than on the east bank. The point sources of pollution in these areas include dumping of waste into the river generated by the portable toilets (City of Johannesburg, 2002).

A more serious water-borne disease in the Jukskei, the occurrence of which has increased in recent years is that of cholera, with 89 reported cases and 8 deaths in the Eastern Metropolitan area in 2000/2001 (City of Johannesburg, 2002).

The Jukskei River is only used for domestic purposes on a small scale, as the municipality is responsible for supplying potable water to the City of Johannesburg. Lack of services compels the use of water directly from the river; however this is only restricted to certain areas. After the outbreak of cholera in the late 1999, the Alexandra community has largely stopped using the water directly from the river (City of Johannesburg, 2002).

1.5. Recreation

Humans undertake several recreational activities around urban watercourses (refer to **Table D.1**). The Department of Sport and Recreation (DWAF, 2002) defines ‘recreation’ as “a process of voluntary participation in a wide variety of activities that are undertaken during leisure times and contributes to the improvement of general health and well being of both the individual and society”.

Table D.1: Active and passive river-based activities (Department of Resource and Energy, 1984)

Active recreation activities	Canoeing, water-skiing, rowing, sailing, swimming, boat fishing, power boating
Passive recreation activities	Fishing, nature exploration, siting by the river, caravanning, picnicking, camping, bird watching, walks, barbecuing.

When these activities are outdoors and water resource-based, it is can be defined as the "use of water for recreational purposes". Such activities may range from leisure and sport to culture and religion, noting that the intent may vary from personal satisfaction to commercial operations. DWAF (1996) defines no-contact recreation as all forms of recreation that do not involve direct contact with water, and includes activities such as picnicking and hiking alongside water bodies. These activities are primarily concerned with the aesthetic appreciation of the river.

Aesthetic features of urban rivers are generally related to preserving or restoring the natural form and appearance of these waters, often by trying to return to the original layout of urban streams with their natural features and riparian vegetation and corridors. Claudia *et al.* (2002) regard aesthetics as a "non-use" or " passive use " as it arises without an individual using the resource in any material sense. Non-use values often reflect a person's desire to preserve or bequeath a resource to future generations rather than consume it.

Urban rivers are also valued for their environmental and ecological functions, providing aquatic and wildlife habitat and educational resources for the urban dwellers. The public has a good understanding of indicators of "bad" water quality such as waste on the surface of watercourses, water of an unusual colour or smell, foam and sediment deposits.

Although recreation is a non-consumptive water use, it requires planning and management. Recreational use of rivers grants significant personal, societal and economic benefits but may also have negative environmental impacts, including social disturbances, and degradation of ecosystems and heritage resources (DWAF, 2002).

Recreational activities may negatively affect the water quality. For example, power boating contaminates the water (release of oils and fuel) and disturbs the aquatic ecosystem, and swimming may introduce water-borne diseases.

Safety is a limiting factor for the recreational use of urban rivers, and is divided into the following two dimensions (www.epa.gov/owowwtr1/watershed/proceed/frederck.html):

1. Physical safety:
   Drowning, health-related issues from the ingestion of polluted water and falling from steep eroded river banks.
2. Personal safety:
   Personal safety pertains to the risk of crime along urban rivers.

The general amenity value for bankside recreation is also threatened by odours, litter, algae, visual pollutants, including recognisable sewage and biological pollutants such sewage fungus and excessive algal growth (Petts *et al.*, 2002).

CASE STUDY
The Upper Jukskei River catchment contains several golf courses (e.g. Huddle Park Golf Course, Observatory Golf Course, Glendower Golf Course), which create impoundments for obstacles and abstract water for irrigation purposes. Gillooly's Farm and Delta Park constitute some of the popular recreational areas within the Jukskei's catchment, and allow for active and passive recreational activities, with the latter also allowing educational facilities. Numerous parks in the Jukskei catchment make use of the river and its tributaries to lend visual appeal. Unfortunately, crime and water pollution threaten the general amenity value for bankside recreation. The social investigations performed as part of the compilation of the Jukskei Environmental Management Framework (City of Johannesburg, 2002) revealed that the most predominant areas of concern around the river pertained to safety in terms of children drowning and crime.

1.6. Economy

The National Water Act (No. 36 of 1998) acknowledges that the management of our country's water resources must promote the economic use of water. When examining the economic aspects of urban rivers it is necessary to consider the goods and services provided by these natural resources.

Economic linkages with urban rivers include agricultural production, municipal and industrial water supplies, hydropower generation, flood control, river navigation, commercial and recreational fishing, and passive use values.

Urban development often makes use of the aesthetic value of watercourses. The natural scenery provided by river frontage invariably boosts property value. Conversely, the lack of maintenance of the adjoining open space and riparian area, crime and river pollution may reduce property values.

A noteworthy commodity of rivers is fish, although urban rivers are either too polluted to sustain fish life or do not allow fishing on a commercial scale.

The recreational use of rivers may be exploited for economic gain, where fees may be asked for the undertaking of such activities. An example is the Dusi canoe marathon, which starts at Camps Drift in Pietermaritzburg and ends at blue Lagoon in Durban with some 3000 paddlers participating.

CASE STUDY

The headwaters of the Jukskei River feed into Bruma Lake. Commercial and business activities occur alongside this dam, and benefit from the visual appeal offered by the water. Unfortunately, sewage pollution caused by upstream discharges has resulted in the eutrophication of Bruma Lake and large quantities of refuse are deposited into the dam. The high costs for the cleaning of the dam is undertaken in partnership with various stakeholders, including the municipality and the private sector.

With a predominantly impervious catchment, the Jukskei River experiences strong flows after rainfall events. The consequential flood damage to infrastructure and property result in high restorative costs (refer to **Figure D.5**). Rehabilitation methods to stabilise the riverbanks and protect man-made structures often fail (refer to **Figure D.6**).

Figure D.5: Stabilisation of previously eroded bank

CASE STUDY (continued)

Figure D.6: **Failure of bank stabilisation effort**

2. MANAGEMENT OF URBAN RIVERS - A SOCIO-ECONOMIC PERSPECTIVE

Some of the existing methods for the management of the socio-economic aspects of urban rivers are discussed below.

According to the Independent Advisory Committee on Socio-Economic Analysis (1998), the following ten steps of community based assessment need to be followed when considering socio-economic impacts on rivers:

1. Understand the catchment;
2. Set goals;
3. Generate management options;
4. Identify effects;
5. Assess effects;
6. Determine the preferred option;
7. Develop impact management strategies;

8. Report;
9. Monitor; and
10. Evaluate and adjust.

Integrated Water Management (IWM) is the management of all the environmental components of a river basin (Cairns, 1991). It can act as an efficient tool which balances optimum functioning of water related natural systems with economic and social demands of the society (Hanušin *et al.*, 2001). Holistic and cross-sector approaches are the most important characteristics of IWM, with the co-ordination of the interest of all stakeholders.

DWAF developed a strategy to manage the water quality of dense settlements. This National Strategy (2001c) addresses DWAF's policy for managing pollution from densely populated areas, describes a process to identify the actual causes of pollution in such settlements, and describes the roll out of this process in priority settlements. A number of reports were produced as part of this project, of which the following are highlighted:

- DWAF's **National Strategy for Managing the Water Quality Effects of Settlements, Planning to Avoid Pollution Problems** (DWAF, 2001a) provides guidelines that integrate water quality and water-related environmental concerns into the settlement planning processes, outline links between settlements sittings and pollution and discuss various planning processes that could be used to ensure planning of settlements.
- DWAF's **National Strategy for Managing the Water Quality Effects of Settlements, the Economic Impact of Pollution Two Towns** (DWAF, 2001b) strives to quantify the health care and other costs that result from diseases that can be associated with pollution from dense settlements.
- Operational guidelines are intended to assist DWAF's Catchments Management Agencies (CMAs), Local Authority Staff and communities to implement the National Strategy.

Amongst others, the purpose of Integrated Development Plans (IDPs) is to grant mechanisms and processes to allow municipalities to achieve social and economic upliftment of communities and to ensure universal access to quality services that are affordable to all. IDPs are thus important tools in managing the socio-economic conditions in urban catchments.

DWAF's Sub-directorate: Environment and Recreation is currently developing and testing a management tool, termed Sustainable Utilisation Plans (SUPs), with regard to the sustainable access, utilisation and development of water resources (Fik, 2004). The SUPs aim to address the use of water for recreation, leisure and tourism purposes.

Census data can be used to determine the population density, employment and the education levels of the people living in an area within the catchments. This information assists the understanding of the socio-economic backdrop of urban rivers.

DWAF's Directorate: Stakeholder Empowerment is furthermore in the process of developing the Social Assessment and Development Framework to be used by the stakeholders for carrying out social assessment studies (Mahasha, 2004).

CASE STUDY
The Jukskei River Environmental Management Framework (City of Johannesburg, 2002) prescribes actions to be taken to mend undesirable changes wrought by human disturbances, with particular emphasis on enhancing recreational attraction. At the outset, information resources in the form of interviews, documents and records, case examples, and observations were explored for national and international trends on urban river restoration and management. The social aspects of the abovementioned study aimed to gauge the feeling of the community toward the river using a variety of tools, which ranged from questionnaires, public meetings, a school competition, workshops and an analysis of development plans along the river. Public participation is of utmost importance in the success of environmental management endeavours. In order for public participation to be effective it is necessary to create an awareness of water quality issues along with an understanding of ways in which individuals and communities are affected by changes in water quality (City of Johannesburg, 2002).

CASE STUDY (continued)

The Local Integrated Development Plans (LIDPs) for the various municipalities through which Jukskei flows were reviewed with regard to whether development proposed in areas along the river is compatible with protection of the river. The LIDPs acknowledged that a proper catchment management plan could assist with the management of the water resource (City of Johannesburg, 2002).

A number of the key role-players contributing to and responsible for a more desirable Jukskei River were consulted during the study. Local authorities are mainly responsible for creating this awareness amongst communities and the public at large as well as implementation of policies and strategies that focus on promotion of sustainable development along the Jukskei River. The communities living along the Jukskei River play an integral part in adopting a sustainable approach towards management of any development along the river. The technical intervention measures recommended to address the stressors associated with the river were in accordance with the views of the community and development philosophies.

E. URBAN AGRICULTURE

One of the land uses that are often overlooked when undertaking urban catchment management is urban agriculture. Although this activity if scarce in worldwide urban areas, in South Africa urban agriculture is frequently encountered. The interaction between urban agriculture and urban watercourses forms the topic of **Section E**.

Agriculture is a wide discipline comprising diverse farming systems and technological patterns. In this section the term agriculture will be used to denote mainly crop farming and animal husbandry.

1. URBAN AGRICULTURE IN AN URBAN RIVER CONTEXT

1.1. Introduction

Agriculture – since its beginnings approximately 10,000 years ago – has significantly modified natural ecosystems in order to yield adequate and permanent staple food supplies for human populations. In creating artificial ecosystems, agriculture inherently interacts closely with pre-existing environmental conditions. Hydrology, soils, climate topography and biology all have major influence over the productivity and profitability of agriculture.

The Green Revolution is described as the introduction of pesticides and high-yield grains and better management during the 1960s and 1970s which greatly increased agricultural productivity. The advent of the Green Revolution changed the prevailing production techniques and processes as it encouraged large-scale agriculture.

Impressive as the Green Revolution gains in agricultural productivity were, they nevertheless came with a high environmental price in the form of increased pollution and depletion of water resources, primarily due to the effects of the package of inputs required by the green revolution plants: pesticide and synthetic fertilisers, as well as consistent watering, achieved in nearly all cases through large irrigation projects. (Conway, 1997).

Lloyd (1992) notes that the changes in land use such as agriculture cause a load to be placed on the aquatic ecosystem. The rise in load resulting from changes in land use far exceeds the rise in load that would emanate from natural variations in climate. Pollution is said to occur when the loading is sufficient to reduce the value of resources to an unacceptable degree.

Loehr (1977) stated that "difficulties in obtaining precise relationships between agricultural practices and environmental problems occur because of the diffuse source of residuals from agriculture and the many factors that are involved, some of which are not controllable by man". Factors that may contribute to the environmental impact of farming include topography, precipitation, cover crop, timing of fertilizer application and cultivation practices.

The variability of waste discharges complicates assessment of the environmental impact of agricultural production. Agricultural wastes frequently are not discharged on a regular basis; food processing wastes tend to be seasonal with production a function of the crop maturity, feedlot runoff is a function of rainfall frequency and intensity, fertilizer applications are timed for ease of distribution and to maximise crop production, and land disposal of wastes are related to the need for disposal and ability to travel on the land (Loehr, 1977).

In South Africa, agriculture accounts for roughly 73% of the total amount of water used, through mainly water abstraction (O'Keeffe, 1986). The demand for water by farming activity is exemplified by Soule and Piper (1992) who describe modern agriculture as a thirsty enterprise. Soule and Piper state that although about one-sixth of the world's cropland is irrigated, this constitutes close to three-quarters of humanity's annual consumption of fresh water.

In the context of this project, urban agriculture is defined as the practice of agriculture (includes crops, livestock, fisheries, forestry activities) within or surrounding the boundaries of cities.

Utilization of water resources on a farm is not restricted to irrigation purposes. Other water uses include watering of animals and cattle dips. The effect on the urban river is through runoff as well as the contribution of farming practices such as fertilizer and pesticide application to the quality of the water resource. Pesticide pollution of surface waters has been known to occur when heavy rains follow field applications (Soule and Piper, 1992).

1.2. Overview of Impacts

The impacts of urban agriculture on an urban watercourse result from activities that are directly linked to the production process. **Table E.1** gives a summary of the impacts of urban agriculture on urban waters. Although the impact sources (e.g. irrigation, damming, pesticide and fertilizer application, dip liquor) may not be applicable to all urban agriculture ventures, the table attempts to provide a complete list of the potential impacts that may occur.

Sections E 1.3 – 1.9 (below) provide a more in-depth discussion on the impact sources related to urban agriculture.

Table E.1: **Impacts of Urban Agriculture on an Urban Watercourse**

Agricultural system	Impacts		
	Source	**Cause**	**Effect**
Crop Farming	Irrigation	• Depletion of water resources	• Dropping groundwater tables • Reduced water levels in rivers • Damage to riparian habitats (Speidel, Ruedisili and Agnew, 1988)
		• Salt water replacing fresh water	• Impotable water sources due to increased salinity (Soule and Piper, 1992)
		• Run-off polluted with salt	• Less tolerant acquatic life become weak and vulnerable (Vesilind and Pierce, 1983)
	Damming	• Reduced water volumes to downstream users • Changes in the micro hydro-climate in the locality	• Reduced water dependent agro-economic activities (www.siwi.org) • Rise in relative humidity and evaporation

Table E.1: **(continued)**

Agricultural system	Impacts		
	Source	**Cause**	**Effect**
Crop Farming	Pesticide and Fertilizer Application	Contamination of surface water resources through run-off or leaching	• Increased nitrate levels, eutrophication (Colvin, 2000) • Elevated cancer rates in humans (Soule and Piper, 1992) • Imbalance in aquatic ecosystem leading to depletion of aquatic populations (Colvin, 2000) • Algal blooms and loss of fishing grounds • Increased purification costs for municipalities
	Soil erosion	Siltation and sedimentation	• Nutrients and pollutants bound to soil particles are transported into the river system • Heavy silt loads cause physical damage to aquatic populations (Vesilind and Pierce, 1983) • Silting up of water resource resulting in a shallower water body.

Table E.1: (continued)

Agricultural system	Impacts		
	Source	**Cause**	**Effect**
Animal Farming	Grazing	Soil erosion and loss of riverside vegetation	• Erosion and concomitant alteration of river bank • Watercourse becomes wider and shallower leading to increases in water temperature and reduced oxygen levels (Wood-Gee, 1998) • Loss of beneficial function of riparian vegetation
	Animal waste	Contamination of surface water resources through run-off, spreading or deliberate disposal	• Organic substances reduce the amount of oxygen available for aquatic plants and animals (Lloyd, 1992)
Animal Farming	Dip Liquor	• Contamination of surface water sources through run-off or deliberate disposal of dip liquor	• Increased concentrations of pesticide in the receiving water • Loss of aquatic populations downstream of the river (Lloyd, 1992)

1.3. Irrigation

Irrigation is the controlled application of water for agricultural purposes through manmade systems to supply water requirements not satisfied by rainfall. Irrigation permits farming in regions that could not otherwise support agriculture and thus increases the earth's capacity to feed the human population (Soule and Piper, 1992).

Irrigation depletes water resources, with a reduction in groundwater and surface water levels. Speidel *et al.* (1988) observe that irrigation results in large volumes of water being "consumed" through evaporation and transpiration. Often less that half the water withdrawn for irrigation returns to a nearby stream or aquifer, where it can be used again.

Irrigation can render water sources impotable where salt water intrudes to replace fresh water when water levels in aquifers get too low. Surface waters also receive salt loads from irrigation in arid regions. Salt loads increase when water evaporates, concentrating the dissolved mineral salts in the remaining water. Irrigation return flows are thus saltier that the water originally withdrawn and add to the saltiness of rivers (Soule and Piper, 1992).

CASE STUDY

No occurrence of formal water abstraction for agriculture was encountered in the study area. In the Soweto area water is transported from the Klipspruit to the crops via buckets (refer to **Figure E.1**) and other suitable containers.

Figure E.1: Buckets (in background) used to transport water from Klipspruit

Diversion of wastewater to irrigate crops was found along a tributary of the Klipspruit, in Soweto (refer to **Figure E.2**).

CASE STUDY (continued)

Figure E.2: Diversion of wastewater to crops

1.4. Fertilizer Application

Farmers use commercially produced fertilizers in order to increase the productivity of the crop through addition of nutrients to the soil. Fertilizer that is applied to the soil and not taken up by the roots of plants is exposed to leaching through the soil and the elements of weather. Nitrate is easily dissolved in water and therefore likely to leach to groundwater. Groundwater discharging into rivers and other surface bodies carries the nitrates with it.

At drinking water concentrations greater than 10 mg/ℓ nitrate-nitrogen (NO_3- N) there is an increased risk to infants of Blue Baby Syndrome (methaemoglobinaemia). Studies are currently being undertaken to determine the increased risk of stomach and oesophagal cancer, due to the consumption of nitrate contaminated water (Colvin, 2000).

An analysis of rivers in the United Kingdom shows, despite considerable year to year variation, a progressive increase in nitrate concentration over the past 30 to 40 years.

Concentrations and rates of increase are highest in the east and centre of the country corresponding to areas of intensive arable cropping (Conway and Pretty, 1991).

1.5. Pesticide Application

In order to prevent, destroy, repel, or mitigate the occurrence of any pests, substances called pesticides are used. Pesticides common to agriculture include herbicides, rodenticides, insecticides and fungicides.

Pesticide contamination of surface waters is dependent on the climate, intensity of the farming techniques employed, the pesticide formulation, the site of application, the soil type, irrigation practices and the amount of pesticide applied (London, Dalvie, Caincross and Solomons, 2000).

According to Conway and Pretty (1991), when a pesticide is applied to crops, most is either taken up by plants and animals or is degraded by microbial and chemical pathways. A proportion is widely dispersed: some is vaporized to be eventually deposited in rainfall, some remains in the soil, while some reaches surface water via run-off or leaching.

Soule and Piper (1992) note that communities that rely on surface water sources can sustain intense exposure at times, particularly when heavy rains follow field applications. Throughout rural America, agricultural chemical use is associated with elevated rates of certain cancers.

1.6. Land Preparation

Land preparation encompasses the activities that occur on the land prior to planting. Land clearing aims to rid the site of unwanted vegetation and to achieve a desired soil structure. Similarly forests have been cleared for growing crops and use as pasture for animal production. This activity disturbs the soil and exposes soil particles to elements of weather such as wind and rain leading to erosion. Conway and Pretty (1991) indicate that the ploughing in of natural vegetation or crop residues results in the release of substantial amounts of nitrate, as soil bacteria break down the organic matter.

Sediments are particles and/or clumps of particles of sand, clay, silt, and plant or animal matter carried in water. Sediment can reduce the recreational value of water and is a carrier of plant nutrients, crop chemicals, and plant and animal bacteria (Loehr, 1977).

Soluble nutrients such as nitrates, when carried as sediments into surface water bodies, contribute to the increased nitrate concentration that may lead to eutrophication. Eutrophication is a process by which a water body becomes rich in dissolved nutrients, often leading to algal blooms, low dissolved oxygen, and changes in aquatic community composition. Eutrophication occurs naturally, but can be accelerated by human activities that increase nutrient inputs to the water body (Vesilind and Peirce, 1983).

In addition, increased sediment loads to a surface water body may result in physical damage to aquatic populations and damage to the riverbed habitat. "The detrimental effects of sediment include interference with the spawning of fish by covering gravel beds; interference with light penetration, thus making food more difficult to find; and direct damage to gill structures" (Vesilind and Peirce, 1983).

CASE STUDY

In Diepkloof, Soweto, subsistence farming occurs on steep slopes alongside the Klipspruit (**Figure E.3**). Soil particles are exposed to elements of weather such as wind and rain leading to erosion. The gradient of the slope amplifies the process of sediment being directed, through run-off, to the receiving watercourse.

Figure E.3: Subsistence farming on steep slopes, adjacent to the Klipspruit

CASE STUDY (continued)

The improper land preparation techniques and farming practices mentioned above can be ascribed to a shortage of suitable farming land inside the urban area, as well as a lack of knowledge by the farming proprietors.

1.7. Grazing

The potential negative impact of animal grazing is prevalent in conditions where pasture land abuts the river's edge. This situation may be exacerbated where there are no structures, such as fencing, in place to restrain animal movement. Wood-Gee (1998) indicates that heavy grazing of river margins and use of rivers for watering livestock leads to loss of riverside vegetation and bankside erosion, which may lead to loss of land.

Loss of riverside vegetation and erosion may alter the river bank, causing the watercourse to widen and become shallower. Increased water temperature with a concomitant decrease in oxygen levels may occur as a direct result of the rivers alteration.

Direct contamination of the watercourse from animal waste is prevalent where animals are allowed to graze right up to the river's edge. Movement of cattle across the urban watercourse contributes to erosion.

CASE STUDY

Absence of grazing land in Soweto results in the use of the open space along the Klipspruit for this purpose. Animals move freely in the floodplain and riparian zone during daily feeding, as shown in **Figure E.4**.

Figure E.4: Mixed herd of cattle, sheep and goats moving alongside the Klipspruit

In the interspersed locations along the Klipspruit, where cattle are allowed to graze freely, erosion of the river banks and loss of riparian vegetation can be noticed. The situation is exacerbated in areas where the cattle cross the Klipspruit from one bank to the other, destabilizing the river banks and contributing to their unsightly shape (refer to **Figure E.5**).

CASE STUDY (continued)

Figure E.5: River Bank Erosion at Cattle Crossing Point

1.8. Animal Waste

The intensive husbandry of livestock produces large quantities of waste concentrated in limited areas. This situation poses an environmental hazard as this waste needs to be disposed off mainly through retail as a fertilizer or application to pasture or cropped land.

Sources of contamination result from inadequate management practices and include the use of unsealed effluent dams for storage of liquid and solid waste, run-off ensuing from the cleaning of stalls and feedlots, run-off from areas where livestock concentrate such as feed troughs, and disposal of dip liquor (Colvin, 2000). Loehr (1974) observed that the greatest contamination occurred during warm weather and periods of low rainfall intensity.

Animal waste is rich in nitrogenous compounds. Discharge of these compounds into the water body may lead to oxidation and result in reduced oxygen levels. The decreased oxygen levels cause stress in fish as the respiratory system tries to adapt to the lower oxygen content. In extreme cases the fish may not be able to extract sufficient oxygen from the water to meet their basic metabolic needs (Lloyd, 1992).

CASE STUDY

The keeping of livestock is common in Soweto (refer to example in **Figure E.6**), and their enclosures are mostly located in the open space along the watercourse, as this area affords adequate space and serves as grazing fields. The proximity of the animal pens to the Klipspruit and the absence of riparian vegetation increase the potential for the waste to reach the watercourse via runoff.

Figure E.6: Cattle enclosure alongside the Klipspruit

1.9. Dams

A surface water body may be dammed up along its length in order to harness water for irrigation. Damming affects the flow of the watercourse and reduces the volume of water reaching downstream water users who may face critical water shortages. This obstruction of the flow of water results in a decline in water dependent agro-economic activities.

Aquatic populations may also be negatively impacted by the reduced flows. Changes in the hydro-climate that result from the reduced flows, will invariably lead to losses of aquatic organisms that do not adapt to the changes in the ecosystem (www.siwi.org).

2. MANAGING THE INTERACTION BETWEEN URBAN AGRICULTURE AND URBAN WATERS

2.1. Impact Assessment

The impact of urban agriculture on urban watercourses is mainly determined by chemical, physical and biological monitoring techniques. **Section C**, which focuses on **Water Quality**, should be consulted for a more detailed discussion on these monitoring methods.

When assessing the reverse of the relationship, in other words the affect of urban rivers on urban agriculture, various factors have to be considered. These may include the following:

1. Crop yield;
2. Crop health; and
3. State of livestock health and safety.

CASE STUDY

The City of Johannesburg undertakes periodic water quality monitoring of the Klipspruit. High turbidity and ammonia levels can be attributed to silt addition from improper land preparation and faecal contamination by livestock, respectively.

Livestock in Soweto was commonly found to be suffering from diarrhoea, which could result from poor nutrition as well as drinking of the Klipspruit's water.

CASE STUDY (continued)

Farming along the Klipspruit is performed on a subsistence level. It is anticipated that the irrigation of crops with polluted water from the Klipspruit will lower the crop production potential, and it will pose potential health hazards to the consumers of the crops.

2.2. Impact Management

2.2.1. Legislation

The National Water Act (Act 36 of 1998) recognizes the National Government's overall responsibility for and authority over the nation's water resources and their use, including the equitable allocation of water for beneficial use, the redistribution of water, and international water matters.

One of the principles promulgated in the National Environmental Management Act (Act 107 of 1998) is that environmental management must be integrated and take into account the effects of decisions on all aspects of the environment by pursuing the selection of the best practicable environmental option.

The Conservation of Agricultural Resources Act (Act no 43 of 1983) requires that effluent should meet certain water quality standards before disposal to surface water or groundwater. These include the following maximum concentrations:

- Electrical conductivity of 250 mS/m;
- 10 mg/ℓ free and bound ammonium-nitrogen;
- 1 mg/ℓ soluble orthophosphate;
- 200 mg/ℓ sodium;
- 0.1 mg/ℓ residual chlorine; and
- 25 mg/ℓ suspended solids.

The Environmental Conservation Act (Act 73 of 1989) stipulates that certain activities, including agricultural processes, land use and transformation and water use and disposal thereof, cannot be undertaken without prior authorisation from the competent authority. A tool that may be employed to assist in the decision-making process is the Environmental Impact Assessment (EIA) procedure.

A guideline that may serve to limit development in proximity to the watercourse is the enforcement of a buffer zone restricting development to outside the 1:50 year floodline.

2.2.2. General

DWAF published the South African Water Quality Guidelines, which specify the water quality requirements of different water uses. The water quality needs for agricultural water use are divided into irrigation and livestock. The South African Water Quality Guidelines for these uses should be employed to determine the fitness of the water to be utilized for agricultural purposes.

Because of the diverse socio-economic and biophysical factors that affect water supply and demand, a river basin perspective is necessary for the effective management of water in agriculture (Gichuki 1998). Factors that may act as indicators and need to be considered from a management function include the following:

- Surrounding land uses;
- Gradient of land;
- Type of farming enterprise being undertaken;
- Mechanisation level of enterprise;
- Production inputs utilised;
- Direct and indirect surface water uses;
- Proximity of farm structures to the river’s edge;
- Vegetation cover along the river banks;
- Visual assessment of the river and its banks; and
- Evidence of erosion, overgrazing etc.

CASE STUDY

In a polluted watercourse such as the Klipspruit urban agriculture is not of critical concern, where sewage discharges and acid mine drainage constitute significant impact sources to be managed.

The City of Johannesburg is charged with the management of the Klipspruit. Central to the management of the waterway is the interpretation of water quality data and addressing pollution sources at hotspots.

DWAF remains the primary authority for the Klipspruit, and acts according to its mandate set out in the National Water Act (Act 36 of 1998). A key activity performed by DWAF includes the regulation of water use.

The Klipspruit forms part of the Klip River Forum, which facilitates stakeholder participation in the management of this water resource. The interest in the forum is water-sector based and urban agriculture does not receive as much attention as industry, mining and other major sectors, which are more relevant in the larger Klip River catchment.

F. STORMWATER

1. STORMWATER IN AN URBAN RIVER CONTEXT

1.1. Introduction

Under natural conditions, vegetation such as forests and grasslands would slow runoff down, allowing it to soak into the ground. However in urban environments, which are characterised by large areas of impervious surfaces, rain is inhibited from soaking into the ground. Impermeable surfaces such as roads, roofs, parking lots and manicured lawns, result in rain accumulating and rushing into stormwater drains, collecting waste and contaminants along the way. Urban stormwater is therefore defined as polluted rainwater that does not infiltrate into the soil and runs off the surface of the land.

The properties of urban runoff (i.e. quality and quantity) are influenced by the structure, and chemical composition of the rocks and soils in the catchment areas whereas the types of pollutants transported by stormwater, their pathways and their loads are affected by regional variability in rainfall and various geomorphologic factors. According to Schoeman *et al.* (2001), two processes enable stormwater to collect and transport pollutants. The first relies on the fact that water is an excellent solvent for numerous substances and is therefore able to transport soluble substances dissolved from atmosphere and urban surfaces. The second process involves raindrops that exert erosive forces on surfaces that can loosen and transport particulate substances.

Freshwater pollution caused by contaminated runoff is referred to as non-point source pollution. Non-point source pollution usually increases with storm events, where the ‘first flush’ effect is evident. ‘First flush’ occurs when pollutants, which have accumulated on hardened surfaces in dry weather conditions, are washed off during the beginning of the rainy season. Urban runoff transports material such as domestic waste, wastewater, heavy metals, oils and sediment. Stormwater drains are linked directly to urban watercourses for easy and rapid transportation of stormwater, resulting in the pollution of urban river courses.

In addition to polluting urban rivers, stormwater also has the potential to increase erosion and/or sedimentation, and the resultant steep riverbanks present a human health risk.

1.2. Sources of Pollutants in Stormwater

Stormwater from urban catchments tends to convey a considerable diversity and quantity of pollutants to the receiving urban waters, with sediments and solids constituting the majority of the load. **Table F.1** lists generic stormwater threats and the associated causes and pollutants.

Table F.1: Generic Stormwater Threats to the Receiving Environment (Planning SA, 2002)

Source	Cause	Key Pollutants
Residential land use runoff	Atmospheric deposition and build up from traffic, washing cars, fertiliser application, poor waste management (domestic refuse), lawn clippings and vegetation.	Increased flow, sediment, nutrients, litter, oxygen depleting material, hydrocarbons, pathogens, trace metals, pesticides and surfactants.
Industrial land use runoff	Atmospheric deposition and build up from traffic, poor waste management, accidental spills and illegal discharges.	Increased flow, sediment, nutrients, litter, oxygen depleting material, hydrocarbons, pathogens, trace metals, pesticides and surfactants.
Commercial land use runoff	Atmospheric deposition and build-up from traffic, poor waste management practices.	Increased flow, sediment, nutrients, litter, oxygen depleting material, hydrocarbons, pathogens, trace metals, and surfactants.
Major road runoff	Atmospheric and vehicular deposition and accumulation	Sediments and nutrients
Building site runoff	Poor management of building site waste and materials	Sediment and litter

Table F.1: **(continued)**

Source	Cause	Key Pollutants
Unstable and degraded waterways	Poorly controlled stock and recreational access, weed infestation, development encroachment, vegetation loss, and eroded and unstable riparian zones.	Sediment, nutrients, oxygen depleting material.
Markets (retail and wholesale)	Poor waste management (litter and commercial waste), illegal discharges, atmospheric deposition and build up from traffic and windblown litter.	Oxygen depleting material, pathogens, sediments, nutrients, litter and surfactants.
Upstream inflows	Runoff from upstream catchments entering via tributaries.	Sediment, nutrients, litter and pathogens.
Open space runoff (e.g. golf course and sporting grounds)	Wash off of nutrients (fertilisers) and litter from public gardens, parks, sporting facilities, golf courses and discharge of poor quality water from ornamental lakes.	Nutrients, litter, oxygen-depleting materials.
Landfill and contaminated areas	Runoff or leaching from landfills and contaminated sites.	Oxygen depleting material, pathogens, sediments, nutrients, litter, trace metals, hydrocarbon and toxicants.
Septic and sewer leakage	Infiltration and overflow from sewerage systems.	Oxygen depleting material, pathogens and nutrients.
Docks and wharves	Runoff from wharf areas including atmospheric deposition, spilt raw products, erosion from unsealed areas and accidental spills.	Sediment, raw product (oxygen depleting materials), oils and greases, trace metals and toxic substances.

An additional contributor of pollutants to stormwater is home industries within informal settlements, such as garages, panel beating, brick making, painting, saloons and informal butcheries. These industries are usually unconnected to municipal sewers and the wastewater joins the surface runoff into the local river system. **Table F.2** lists the possible pollutants from home industries.

Table F.2: Possible Pollutants from Home Industries (Mvungi *et al.*, 2002)

Activity	Possible Pollutants
Motor spares, garages, car washing, painting	Chemical Oxygen Demand (COD) pollutants, Total Suspended Solids (TSS), Iron (Fe), Nickel (Ni), Copper (Cu), Zinc (Zn), Lead (Pb)
Car washing and Brick making	TSS, COD, ammonia (NH_3), phosphates
Food processing i.e. maize milling	TSS, nitrates, phosphates, COD, Fe, Cu

CASE STUDY

Alexandra is situated in the upper catchment of the Jukskei River. Its original stands (size of 500-600m^2) are characterised by sizeable houses of reasonable stock. According to the Greater Johannesburg Metropolitan Council (2000a) a common occurrence in Alexandra is 3–6 separate rooms ('backyard shacks') built in the original gardens, each usually housing an additional family who rent from the main householder. This contributes to the lack of open and permeable space in an already dense, over-populated area.

Stormwater from Alexandra is severely polluted by sewage (due to lack of infrastructure and blockages of existing sewerage systems), wastewater, litter and other waste generally associated with dense settlements.

CASE STUDY (continued)

Figure F.1 below illustrates the lack of pervious surfaces in Alexandra.

Figure F.1: Aerial photograph of a portion of Alexandra indicating high densities (particularly on west banks)

1.3. Impacts of Stormwater on Urban Rivers

Fast flowing runoff that empties into an urban watercourse typically results in the destabilisation of stream banks, which damages riparian vegetation and widens stream channels. This in turn leads to lower water depths during dry periods, higher than normal water levels during wet periods, increased sediment loads and water temperatures. These conditions present an inhospitable environment for aquatic biota, causing poor biodiversity and water that is unfit for human use (e.g. recreation, domestic and agricultural).

Some of these key impacts of stormwater are discussed in more detail below (overleaf).

1.3.1. *Sedimentation*

Urban areas have a high sediment yield that can be attributed to land disturbance in the form of construction sites, mining operations, land clearing, etc. Runoff transports these high sediment loads to urban watercourses.

Sedimentation adversely affects urban watercourses as follows:

- Water quality impairment (e.g. increase in turbidity);
- Degradation of habitats;
- Clogging of gills (fish and invertebrates);
- Interfering with the feeding of aquatic biota;
- Limiting photosynthesis;
- Transferring of nutrients and other pollutants downstream; and
- Filling of channel and detention/retention facilities, thereby causing a loss of flood conveyance and storage abilities.

CASE STUDY

Large-scale development (especially residential) occurs in the Jukskei River Catchment, with the consequential disturbance of open spaces. This results in high turbidity levels in the river, which is worsened during rainfall events. Refer to **Figure F.2** for examples of sedimentation in the Jukskei River.

CASE STUDY

Figure F.2: **Sedimentation in the Jukskei River**

1.3.2. Accumulation of Litter and Other Waste

Litter that accumulates on streets, pavements and other urban areas are conveyed to urban rivers via the stormwater system. Illegal dumping also occurs frequently in urban areas, where solid waste is disposed off in open areas and washes into urban water systems. The accumulation of litter and other waste within an urban river threatens not only the environment but is probably the greatest threat to human health. This is particularly evident in dense informal settlements.

Informal settlements are often located adjacent to urban streams due to the availability of open space and the use of the waterways as a primary source of water. These settlements generally have no stormwater systems and poor sanitation infrastructure, promoting the spread of disease and posing threats to human health.

CASE STUDY

Litter accumulates in stormwater inlets through the direct disposal by the public, street sweepers and runoff. This problem is especially evident in the Johannesburg Central Business District (CBD), which constitutes the upper catchment of the Jukskei. Refer to photographs contained in **Figure F.3**.

Figure F.3: Litter accumulation in stormwater inlets, in Johannesburg CBD

1.3.3. Flooding

Rapid influx of stormwater into urban rivers following rainfall events results in flooding. According to Stephenson (2002), the magnitudes of floods are affected by the following:

- **Rainfall** – intensity, duration, movement, spatial distribution, time variation, preceding rain;
- **Other sources of water** – dew, hail, groundwater;
- **Man induced floods** – through dam break, pumping, conduit burst;
- **Topography** – slope gradients and flow lengths;
- **Catchment** – cover, roughness, reservoirs, temperature, shape;
- **Ground** – moisture, permeability, capillary suction, absorption, porosity, depth;
- **Channel** – networks, lengths, depths, cross sections, gradients;
- **Vegetation** – structure, height, rooting system; and
- **Man-made factors** – cover, buildings, usage, drains.

Flooding in dense settlements is a common occurrence with the associated threats to human life and property. The high densities of informal settlements, the erection of informal dwellings within 1:100 year floodline, and the blockages of channels (by shacks and waste) exacerbate risks. In rainy periods access roads through the settlements act as stormwater channels carrying solid waste, litter and excreta to the rivers (Wood *et al.*, 2001).

The resulting problems of floods include threats to public health, damage to infrastructure, erosion of the banks and channel, and damage to riparian vegetation.

CASE STUDY

Flooding often occurs in the Jukskei River, and is mainly ascribed to ongoing development in the catchment, which has created vast areas of impervious surfaces, intense afternoon thunderstorms that are common on the Highveld, and steep gradients along the river's course.

The after effects of flooding are most noticeable when examining the structural damages to the river (**Figure F.4**). Examples of failed structures that were unable to withstand the strong flows of the Jukskei are provided in **Figure F.5**. More tragic consequences of flooding in the Jukskei River and its tributaries are the loss of human life, which are often associated with flash floods.

Figure F.4: **Erosion of the Jukskei River's banks**

Figure F.5: **Pylon at risk (top left), damaged weirs (top right and bottom left) and exposed sewer manhole (bottom right)**

1.4. Assessment Considerations

Poorly managed stormwater has the potential to increase the frequency and intensity of flood events. Thus flooding could occur on a regular basis at successively higher water levels.

According to the City of Johannesburg (2002), the area directly adjacent to a watercourse that may be inundated regularly (i.e. once every few years) is referred to as the waterway. No development should be permitted in the waterway, as there is a real and frequent danger to property and human life. At a higher ground level, such as within the 25-year flood line, there is still a risk of flooding which could endanger property and life, but it does not occur frequently enough to be of momentous concern. The area within the boundaries of this flood line is called the flood zone, which comprises the waterway and the flood plains.

Higher above the flood zone, flooding is likely to occur even less frequently and this area is referred to as the flood fringe. This extends to the limits of the 50-year flood line. In recent years, the National Water Act (No. 36 of 1998) now also requires the 100-year flood to be indicated on development plans.

The abovementioned flood zones are depicted in **Figure F.6**.

The danger or hazard associated with flow is generally expressed in terms of a diagram such as the flood hazard diagram and index (City of Johannesburg, 2002). An additional assessment tool is a risk index. This index considers the risk, or probability, of the hazard (i.e. flooding) occurring. Thus, if the hazard is only likely to occur with a probability of 1% in any single year, it may be tolerable. However if that hazard occurs more frequently (e.g. at least once every year) it may be intolerable. This risk factor can be evaluated in terms of the recurrence interval of the flood. Thus a high risk index could be associated with floods occurring more often than once in 20 years and an intermediate risk index for floods occurring with a recurrence interval between 20 and 100 years, and low risk index for events which occurred less frequently than once in 100 years.

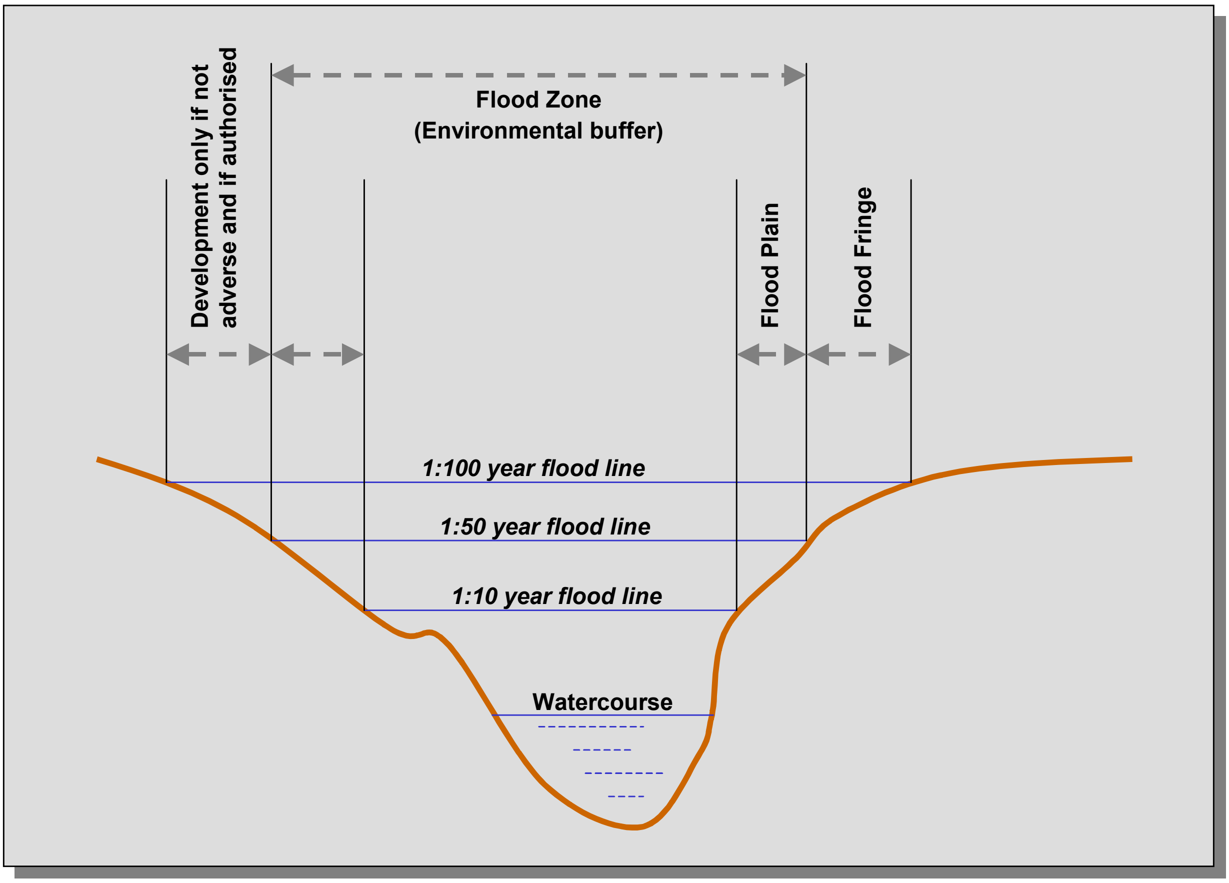


Figure F.6: **Flood Zones (adapted from City of Johannesburg, 2002)**

Hydrologic models, which are simplified, conceptual representations of a part of the hydrologic cycle, are primarily used for hydrologic prediction and for understanding hydrologic processes. Hydrologic models can be based on data or on process descriptions. The former models use mathematical and statistical concepts to link a certain input (e.g. rainfall) to the model output (e.g. runoff). The latter models can be far more complicated and attempt to represent physical processes such as surface runoff, subsurface flow, evapotranspiration, and channel flow.

1.5. Management Considerations

1.5.1. Legal Framework

The following statutory arrangements govern stormwater management (list not exhaustive):

- **National:**
  - Constitution of the Republic of South Africa, 1996 (Act 108 1996);
  - National Environmental Management Act, 1998 (Act 107 of 1998);
  - National Water Act, 1998 (Act 36 of 1998);
  - Municipal Systems Act, 2000 (Act 32 of 2000);
  - National Building Regulations and Standards Act, 1977 (Act 103 of 1977);
- **Provincial:**
  - Land use planning acts and ordinances;
- **Local:**
  - Stormwater management by-laws;
  - Stormwater management planning and design guidelines;
  - Catchment management plans and policies; and
  - Spatial development frameworks.

1.5.2. Planning for Stormwater Management

According to Hammer (1989), the objectives of stormwater management include the following:

- Provide surface drainage;
- Control floods;
- Control erosion and sedimentation;
- Reduce pollutants in runoff; and
- Provide aesthetic amenities, including open spaces, recreation and waterfront property.

To achieve the above goals, the volume, rate, timing and pollutant load of runoff after development must be similar to predevelopment conditions. A stormwater management system must be an integral part of the site planning process for every project (Hammer D.A., 1989). Stormwater control within a new area must be a major consideration when planning the layout. Stormwater management, flood control, capital cost of installation and maintenance are dependent on the basic layout of a development (South African Institution of Civil Engineers, 1981).

An urban Stormwater Master Plan (USMP) is recommended to provide the specific requirements for urban stormwater management in an existing council area. The USMP should provide information on a number of stormwater related issues including existing and proposed flood plane zones/maps, water quality device locations, wetlands, detention basins, retention basins, availability of open spaces for the construction of stormwater infrastructure, soil types and adjacent development requirements. (Planning SA, 2002):

Schoeman *et al.* (2001) make the following recommendations to assist planners, developers and managers to avoid some of the most obvious problems associated with urban runoff:

- No new urban developments should be allowed to incorporate bucket latrine systems and all bucket latrine systems must be phased out;
- Pit latrine systems should be phased out as soon as possible for all developments that are located on sandy or permeable soils;
- All urban developments should be provided with effective garbage collection services and indiscriminate dumping must be avoided;
- All streets in urban areas should be cleared regularly of sand and other debris to minimize the risks of blockages in the stormwater drainage system;
- All stormwater grids should be inspected regularly. Ideally these grids should be cleared or cleaned on a weekly basis during the dry season and after each storm during the rainy season;
- No human inhabitation of any sort should be allowed in or near to any stormwater detention basins or flood control facilities. All squatters who presently occupy sites on such locations should be provided with alternative locations as a matter of urgency;
- The number of people occupying each residential plot should be controlled in accordance with the level of services provided (i.e. number of toilets; potable water supply points);

- The quality of water emerging from all stormwater outfalls should be sampled regularly to determine whether or not the stormwater outfalls are contaminated; and
- Bathing and collection of water for human use from watercourses that receive any stormwater discharge should be prohibited at all times.

Stormwater management programmes in urbanising areas retard storm runoff, and in this way counter the rapidity of runoff from impervious surfaces (Whipple, 1983). Design solutions need to consider the most cost effective approach and seek to maximise the social and environmental benefits that can be built into the solution (Planning SA, 2002). However, in established and built up areas where land is scarce and expensive, and the opportunity to build in environmental improvements is limited, a different range of solutions may need to be considered.

CASE STUDY

On a catchment level, stormwater management of the Jukskei is included in the Metropolitan Catchment Management Policy and Catchment Management Plan. The Catchment Management Strategy (CMS), which is a process for integrating environmental, economic and social considerations in management of catchment areas, will serve as the overarching management mechanism.

The Johannesburg Roads Agency (JRA) is the municipality’s utility charged with managing roads and stormwater. JRA is involved with the implementation of Site Development Plans, which need to be submitted by developers and approved by JRA prior to development. Each development further requires a stormwater management plan and detention facilities. The objective is that post-development stormwater run-off should not significantly exceed the predevelopment values in peak charge for any given storm.

CASE STUDY (continued)
Detention ponds receive stormwater before discharging it into the Jukskei River, which attenuates runoff and allows pollutants to settle out to prevent or reduce contamination of the watercourse.

1.5.3. Stormwater Management Measures

Table F.3 suggests some stormwater management practices that could be implemented in an urban catchment context, and provides the motivation behind the recruitment of these measures.

Table F.3: Stormwater Management Practices (Stephenson, 1981)

Purpose	Method	Reason
Peak Flow Rate Attenuation	Storm monitoring	Flood prediction
	Detention storage	Flood routing
	Channel storage	Flood routing
	Gravel storage	Retardation
	Rooftop storage	Routing and lag
	Parking lot storage	Routing and lag
	Disconnected impervious areas	Infiltration and attenuation
Runoff Volume Reduction	Retention storage	Removal of flow
	Diversion	Subtraction of flow
	Soakaways	Infiltration
	Basin recharge	Increase ground water
	Infiltration	Flow reduction
	French drains	Seepage
	Swales	Retard flow, infiltration
	Porous pavements	Infiltration
	Contour ploughing	Infiltration

Table F.3: **(continued)**

Purpose	Method	Reason
Provision for flooding	Insurance	Compensation
	Building control regulation in flood zone	Limit damage
	Flood warning	Evacuation/diversion
Catastrophe Aversion	Evacuation	Structural failure
	Sandbagging	High water levels
	Emergency overflows	Water flow control
	Weir strengthening	Dangerous flood levels
	Water tank	Polluted water supplies
Erosion Control	Berms	Settling
	Vegetation	Stabilisation, retardation
	Rockfill	Flow control
	Mulching	Runoff control
	Fertilizing	Encourages vegetation
	Settling basins	Catching sediment
	Sediment removal	Basin renewal
	Screen	Detritus
	Centrifuge	Separation
	Contour ploughing	Surface storage
Pollution Control	Street sweeping	Catching solids
	Street vacuuming	Catching fines
	Street flushing	Total removal
	Street deicing	Ice removal
	Catching first flush	Catches most concentrated pollutants
	Refuse removal	Avoiding pollutants
	Storage	Settling
	Aeration	Biochemical oxidation
	Chemicals	Neutralisation, precipitation
	Comminuters	Grinding large solids

Table F.3: (continued)

Purpose	Method	Reason
Pollution Control (cont.)	Flotation	Scum, emulsion, oils
	Legislation	Enforcement of standards
	Summons/fines	Discouragement
	Waste dump isolation	Runoff detention
	Grassing street verges	Catching fines, scum

CASE STUDY

In the Jukskei River Catchment the stormwater control system comprises of kerb or grid inlets, which are provided on the roadways. These inlets are connected to an underground pipe network. As the water travels down the branches of the pipe network the volume of the water becomes too large for pipes, therefore the system is changed to culverts (i.e. boxlike underground conduits). The stormwater then flows into concrete canals and eventually into the river.

The headwaters of the Jukskei are canalised to ensure rapid conveyance of stormwater from the CBD (refer to **Figure F.7**).

Figure F.7: Canalised section of Jukskei's headwaters

CASE STUDY (continued)

Stormwater discharges disturb the Jukskei's banks and channel (refer to **Figure F.8**). The river bank at these outlets is commonly protected with hard engineering structures such as gabions.

Figure F.8: River structure disturbance at stormwater outlet

G. INDUSTRY

As both a water user and polluter, the industrial sector commands attention when attempting to understand and manage urban rivers. As such, the focus of this section is on the interaction between urban watercourses and industrial activities.

1. DEFINING INDUSTRIAL POLLUTION IN AN URBAN RIVER CONTEXT

1.1. Introduction

Industrial wastewaters usually contain complex mixtures of chemicals. For many of these chemicals little is known, so much so that not even the chemical formula have been identified, much less the specific threats these toxic chemicals may present to human health (Vesilind, 1983).

Industrial wastewater can be toxic to the environment and has the potential to drastically alter river ecology. Major categories of pollution and/or threats that industrial effluents pose to urban river health include (Campbell, 2001):

1. Temperature;
2. pH;
3. Inorganic pollutants and turbidity;
4. Organic pollutants and nutrients and
5. Other.

1.2. Categories and Effects of Industrial Pollutants

1.2.1. Temperature

Temperature can significantly affect physical, chemical and biological processes as well as microbial activity and hence the rate at which organic waste is broken down by bacteria (Campbell, 2001). When industries release heated water into river systems it can cause devastating changes to the ecological functioning of the river (Stream Pollution, 2005). Heated water results in a decrease in the solubility of oxygen and an increase in the rate of biodegradation of organic matter (Best, *et al.*, 1977; Campbell, 2001). Heated water has a lower density and thus collects in the top layers of the river. Combined, the factors result in aquatic life suffering due to the lowered oxygen content of the water. Temperatures higher than 35^{O}C will inhibit nearly all biochemical processes and destroy aquatic life (Department of Environmental Affairs, 1990).

Sources of heat pollution include nuclear, natural gas and coal power plants as well as cooling operations in petroleum refining, pulp and paper, iron and steel and chemical manufacturing industries (Kneese *et al.*, 1968).

1.2.2. pH

The primary contaminants responsible for changes in the pH of water is inorganic pollutants in the form of ions. Subsequent changes in the pH of watercourses will alter the potential toxicity of various chemicals to aquatic organisms (Dallas and Day, 1993). For instance aluminium will form toxic Al^{3+} ions at low pH (<5).

High concentrations of acids (which causes the pH to drop below 6) leads to eye irritations in swimmers, corrosion on boats, the decay of fish nets and so forth. A negative effect on aquatic life will also be evident when river water is alkaline (pH values >6) (Department of Environmental Affairs, 1990). At certain pH levels, the valence of metallic elements is changed allowing it to be taken up by plants and other aquatic animals and stored in the tissues thus facilitating the accumulation of heavy metals up the food chain. Once the aquatic animal or plant dies, the heavy metals are released again into the water (Campbell, 2001).

1.2.3. Turbidity

Most inorganic pollutants are chemically inert and are transported downstream unaltered. However once the flow of the watercourse slows sufficiently, these insoluble forms of inorganic pollutants settle out and coat the bottom of the river. This results in the inhibition of the biological activity of the benthic layer and may even cause turbidity.

Turbidity is a measure of reduced transparency of water due to suspended solids. If the water is turbid, there is deterioration in light transmission that limits photosynthesis in aquatic plants (Kirk, 1985). Similarly to inorganic pollutants, when suspended solids settle out, it may smother aquatic organisms leading to the retardation of benthic activities (Campbell, 2001).

1.2.4. Organic pollutants

Organic pollutants are non-conservative variables in that they undergo some form of chemical or biological change. The primary effect of organic pollutants in a river system is the depletion of stored dissolved oxygen due to the numerous oxidations reactions (by various bacteria) that occur. Other organic pollutants such as pesticides are not easily broken down and have an accumulative and lasting effect, which can be toxic to a range of aquatic organisms, in particular fish (Campbell, 2001).

Organic pollutants also include nutrients such as inorganic forms of nitrogen and phosphorus. The aforementioned nutrients are responsible for the eutrophication of streams. The primary source of nutrients is the dissolved nutrients contained in runoff from urban catchments.

In some of the South African urban areas, the capacity of rivers to limit the deleterious effect of organic pollution by dilution has reached saturation point. Thus the quality of water in many areas is deteriorating as a result of the increased return-flows of saline effluent (Department of Environmental Affairs, 1990).

The following industries are primarily responsible for the release of organic pollutants into aquatic environment (Department of Environmental Affairs, 1990):

- Fisheries and meat processing industries;
- Industries that process by-products from other industries, such as tanneries and bone-meal, blood-meal and carcasses processing industries;
- Grain processing industries, including beer breweries and starch production units;
- Fruit and vegetable preserving and processing industries;
- Wine and brandy distillers; and
- Sugar refineries and the processors of food products from sugar and the by-products of sugar refineries.

1.2.5. Other

See **Table G.1** for a comprehensive list of industrial pollutants and possible sources.

<u>Table G.1:</u> Chemical Substances in Industrial Wastes (after *Best et al.*, 1977)

Substances	Present in waste water from
Free chlorine	Laundries, paper mills, textile bleaching
Ammonia	Gas and coke manufacturers, chemical manufacturers
Fluorides	Scrubbing of flue gases, glass etching, atomic energy plants
Cyanides	Gas manufacturers, plating, case-hardening, metal cleaning
Sulphide	Sulphide dyeing of textiles, gas manufacturers, viscose rayon manufacturers
Sulphites	Wood pulp processing, viscose film manufacturers
Acids	Chemical manufacturers, mines, iron and copper pickling, D.D.T manufacturers, brewing battery manufacturers
Alkalis	Cotton and straw kiering, wool scouring, cotton mercerising, laundries
Chromium	Plating, aluminium anodising, chrome-tanning
Lead	Battery manufacturers, lead mines, plant manufacturers
Nickel	Plating
Cadmium	Plating
Zinc	Galvanising, zinc-platting, viscose rayon manufacturers, rubber processing
Copper	Copper plating, copper pickling, cuprammonium rayon manufacturers
Arsenic	Sheep-dipping
Sugars	Dairies, breweries, preserve manufacturers, glucose and beet sugar factories, chocolate an sweet industries
Starch	Food processing, textile industries, wallpaper manufacturers
Fats, oils and grease	Wool scouring, laundries, textile industries, petroleum refineries, engineering works
Phenols	Gas and coke manufacturers, synthetic resin manufacturers, textile industries, tanneries, tar distilleries, chemical plants, dye manufacturers
Formaldehyde	Synthetic resin manufacturers, penicillin manufacturers

CASE STUDY

Industrial land uses in the Upper Jukskei are indicated in **Figure G.1**.

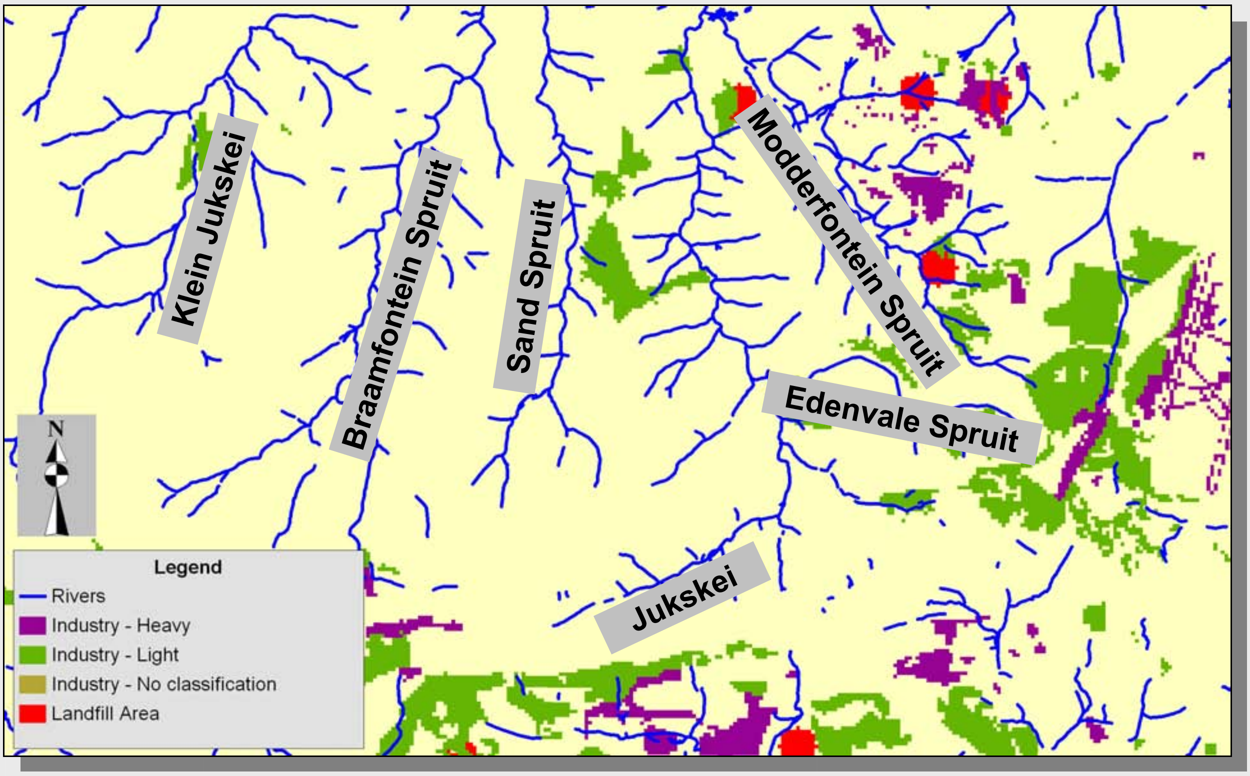


Figure G.1: Industrial land uses in the Jukskei River

Most industries in the Upper Jukskei Catchment discharge effluents to the municipal sewerage systems. However, surface water pollution occurs through surface spills, illegal connections to stormwater systems and deliberate illegal discharges.

Industrial activities along the main stem of the Upper Jukskei mainly occur within the headwaters, including Doornfontein, New Doornfontein and Troyeville (refer to **Figure G.2**). Additional noteworthy industrial areas include Kew and Marlboro.

CASE STUDY (continued)

Figure G.2: Arial perspective of industrial areas in Jukskei River's headwaters

The Edenvale Spruit (also known as the Eastleigh Spruit) drains the Eastleigh light industrial area, as well as part of Germiston and Isando, and thus contributes industrial-related pollutants to the Upper Jukskei River.

Various permitted dumping sites are situated within the Upper Jukskei's catchment, including the Linbro Park landfill and the Randburg municipal dumping site. Unlawful dumping occurs throughout the catchment, with one particularly large site located adjacent to the N3 Highway.

Significant point and diffuse sources of industrial pollution in the Upper Jukskei include the Kelvin Power Station and the AECI factory (refer to **Figure G.3**), which contaminate the Modderfontein Spruit.

CASE STUDY (continued)

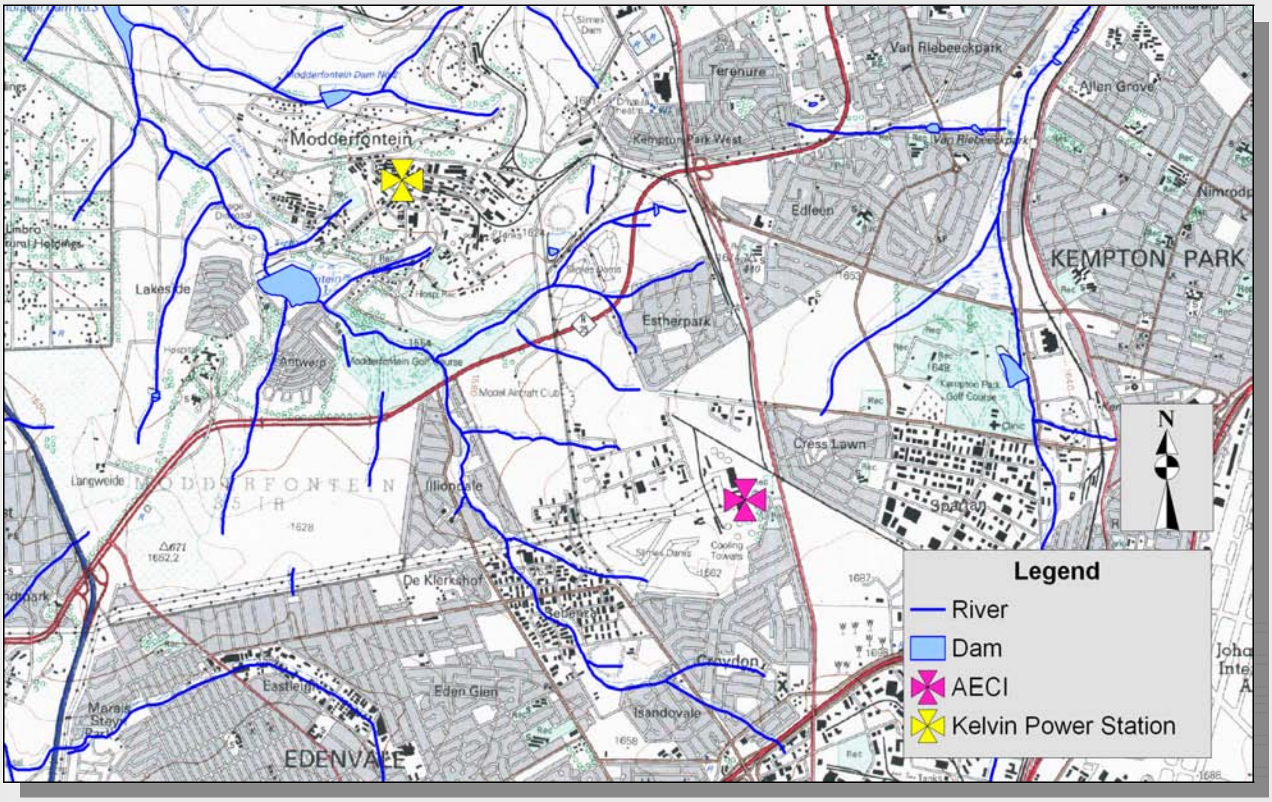


Figure G.3: Map indicating positions of Kelvin Power Station and AECI factory

1.3. Management Considerations

Water use and the potential for water conservation vary amongst industries. This is due in part to the variation in the industrial process. Some industrial processes include direct consumption as part of the manufacture of their products. Others may use very little water in direct manufacturing but may use large volumes of water for cooling or cleaning purposes (Riverol, Pilipovik and Carosi, 2006). Aspects that need to be considered when managing any industry which uses water include legal implications and obligations as well as any guidelines established by government or scientific organisations.

Section 21 of the National Water Act (No. 36 of 1998) lists the disposal (in any manner) of water which contains waste from, or which has been heated in, any industrial process as a water use. DWAF, as the custodian of our country's water resources, regulates this water use through a system of effluent discharge permits or licences. Licensed effluent dischargers are required to routinely monitor the quantity and quality of their effluent, and the results are submitted to DWAF. DWAF also conducts random audits to ensure compliance with the permits.

Industries can also undertake self-regulation by implementing an Environmental Management System (EMS) such as ISO 14000. In order to obtain ISO 14001 accreditation the relevant industry must *inter alia* demonstrate compliance with all legal requirements and verify that environmental risks are identified and mitigated against.

The Department of Environmental Affairs (1990) proposes the following management recommendations to ensure cleaner effluent with lower production costs:

a) The careful planning of the location of the industry

The industry should be located in such a way that the polluted effluent is least harmful to the water environment. For example, an industry with a high concentration of non-poisonous salts in its effluent could be located at the coast and the effluent could be discharged directly into the sea.

b) A cleaner and better organised factory

The inefficient handling of raw materials, the faulty use of chemicals, inefficient process control, poor design and layout of factories, bad planning of the water circulation system and ignorance about the principles of separation of wastes can result in excessive water pollution.

c) Effluent separated at the source and treated separately

Organic polluted effluent can be discharged directly into the municipal sewage system, while effluent with a high concentration of salts could be disposed of by means of evaporation.

d) The recycling of water

Effluent from one process can often be used for other processes within a factory. This is known as the hierarchical use of water. The use of water can be planned such that although the water is continuously degraded, it could still be used successively for the next process.

e) The treatment of sewage effluent

Treated sewage effluent is already being used for the irrigation of gardens, golf courses, sport fields and for the growth of agricultural crops. South Africa took the lead in purifying of sewage effluent to such an extent that it is even suitable for household use, however a limiting factor is the costs involved in the purification process.

The wastewater from industries can be purified to a certain extent by wetlands. Wetlands are generally very effective in reducing (by up to 95%), the concentrations of nitrogen, pathogenic bacteria and heavy metals in wastewater. However, their efficiency in reducing phosphorous and organic matter concentrations varies widely, with some wetlands removing over 90% and others removing very little. Heavy metals and refractory organic compounds are removed from industrial wastewater by both plant and sediment uptake (Rogers, 1985). The mechanisms that are available to improve the water quality include (IWA Specialist Group, 2001):

- Settling of suspended particulate matter;
- Filtration and chemical precipitation through contact with the substrate and litter;
- Chemical transformation;
- Adsorption and ion exchange on the surfaces of plants, substrate sediment and litter;
- Break down and transformation and uptake of pollutants and nutrients by microorganisms and plants; and
- Predation and natural die-off of pathogens.

Constructed wetlands are a cost-effective, environmentally friendly and technically feasible approach to the treatment of industrial wastewater and run-off for several reasons (IWA Specialist Group, 2001):

- Wetlands can be less expensive to build than the other treatment options;
- Operation and maintenance expenses (energy and supplies) are low;
- Operation and maintenance require only periodic, rather than continuous, on site labour;
- Wetlands are able to tolerate fluctuations in flow;

- Wetlands are able to treat wastewater with low organic loads (too low for activated sludge);
- They facilitate water reuse and recycling;
- They provide habitat for many wetland organisms;
- They can be built to fit harmoniously into the landscape;
- They provide numerous benefits in addition to water quality improvements such as wildlife habitat and aesthetic enhancement of open spaces; and
- They are an environmentally sensitive approach that is viewed with favour by the general public.

Some industrial waste can be treated to make it less hazardous. For example, chemicals or bacteria can be added to waste or different types of waste can be mixed so that they neutralise each other. Another way to reduce the toxicity is to incinerate the waste, however, if the leftover ash is hazardous, it must be properly disposed at a hazardous waste landfill (DWAF, 1998).

H. WASTE

This section explores one of the most pressing environmental problems in urban areas, namely waste. With the variety of land uses and human activities which occur in urban catchments, large quantities of waste products are generated. Urban waterways are often the recipients of these unwanted materials, with consequential impoverishment of the freshwater environment.

1. Defining Waste in an Urban River Context

1.1. Introduction

Surface water bodies are progressively subject to increasing stress as a result of environmentally degrading processes primarily related to anthropogenic activities (Massoud *et al.*, 2005).

Urbanisation and industrialisation have led to a large increase in stress on the urban water resource. Degradation of these watercourses is attributed mainly to the lack of environmental considerations in planning and management of the urban systems.

Waste generation, transportation and disposal in Gauteng are considered one of the biggest challenges facing the Province. Unsustainable production and consumption are increasing the quantities and variety of environmentally persistent wastes at unprecedented rates.

The common causes of water pollution in urban centres are poor sanitation facilities, unchecked disposal of municipal sewage and solid waste, non-availability of minimum flow in rivers to utilise their assimilative capacity, operation and maintenance problems in treatment plants for municipal sewage, illegal dumping and industrial effluents, outdated technology and scale of operation in small scale industrial units making it difficult to adopt effective pollution control measures, and faulty land use (Biswas, 2003).

The harmful effects of unmanaged waste can be short-term (aesthetic effects) or long-term which may entail irreversible damage to the natural resources (e.g. water, soil, fauna and flora) (DWAF, 1998).

Waste-related impacts are dependant on numerous aspects such as the waste type and quantity, as well as the current state of the receiving watercourse. Rivers are ‘sinks’ for waste in their catchment areas. Even waste from activities carried out a long way from the river can end up in the river system. The movement of waste into rivers may be very obvious with pollutants such as domestic garbage, but the movement of pesticides and sewerage into rivers is less so (AusAID, 2000).

The National Waste Management Strategy (Waste Minimisation and Recycling Team, 1999) views waste as an “undesirable or superfluous by-product, emission, or residue of any process or activity that has been discarded, accumulated or been stored for the purpose of discarding or processing”. In the urban arena waste may take on a host of forms, which ranges from various states (i.e. gaseous, liquid or solid) and types, depending on its source.

1.2. Waste–related Impacts on Urban Rivers

1.2.1. Sources

Waste that ends up in an urban river as a result of domestic, industrial, agricultural and recreational activities of human beings can be categorised under non-degradable wastes and degradable wastes. Non-degradable wastes may be diluted and may be changed in form, but they are not reduced in weight, for example chlorinated pesticides from agriculture and plastics. Degradable wastes are reduced in weight by the biological, physical, and chemical processes, which occur in the natural waters (Kneese and Bower, 1968).

Waste in waterways can also be classified as organic or inorganic pollutants. Organic pollutants are defined as carbon-containing compounds that are discarded into the environment. They can be divided in the following two groups:

- ‘Once living’ matter such as sewerage and vegetable waste; and

- Synthesised carbon based compounds, including some pesticides such as DDT.

The sources of 'once living' organic pollution are generally agriculture, household and industry. Examples include rubbish containing decomposing fruit, vegetables and meat, and human and livestock sewerage. The sources of the more insidious synthesised carbon-based compounds are primarily agriculture and industry.

Inorganic pollution is defined as chemical substances of mineral origin that are discarded into the environment. This pollution is generally of an industrial or agriculture origin. Examples include heavy metals, sulphur and nitrates. Some inorganic wastes (heavy metals) tend not to affect oxygen levels in the water but settle in the silt in rivers, clouding the water and coating the riverbed (AusAID, 2000).

Industrial waste that is discharged, frequently contain inorganic or metallic salts, synthetic organic chemicals and other materials, which may be toxic and corrosive, may impart colour or taste to the water and/or may produce odours. Storm runoff from agricultural land carries clay, silt, fertilisers, organic material and bacteria into the watercourses.

Waste can be general waste, which comes from our homes, gardens, offices and building site, or hazardous waste containing explosive, corrosive, flammable, poisonous, infectious or other dangerous substances (DWAF, 1998). Some of the waste generated may be bulky (Wilson, 1977). Parks and commercial enterprises generate quantities of solid wastes which are too large and will take up large spaces in landfills, for example used and old furniture, appliances, tree trimmings, logs, construction and demolition debris. All these types of waste can flow into rivers from stormwater systems, illegal dumping, wind movement and landfill sites.

Some pollution comes from sources which can be pin-pointed, for example a factory or intensive agriculture discharging its waste into a drain. These are called 'point' sources. However, many of the pollutants which enter rivers come from a wide area, for example fertilisers used throughout a farming area, or on parks and gardens. These 'non-point' (diffuse) sources are harder to manage (Government of Western Australia, 1997).

In the ensuing sections, sources of waste are discussed under physical waste, inorganic waste and organic waste.

a) <u>Physical Waste:</u>

Physical waste includes undissolved solid substances like silt or sediment from mining, dredging, erosion or building sites, street litter from illegal dumping or through stormwater drains, dyes which changes the colouring or creates muddiness of the water, and foam on the water as a result of artificial detergents or industrial wastes, especially from the textile, paper and pulp mills.

CASE STUDY

The Klipspruit River is an integral part of the greater Kliptown area, in the south of Johannesburg. The river follows a route that passes industrial, mining (refer to **Figure H.1**), residential (including high density low cost housing - refer to **Figure H.2**) and commercial land-use types. Each activity has a unique impact on the river.

<u>Figure H.1:</u> Silt from mining activities in Klipspruit Catchment (JDA, 2002)

<u>Figure H.2:</u> Litter at stormwater outlet in Kliptown (JDA, 2003)

b) <u>Organic Waste:</u>

Organic waste comprises of human, plant and animal wastes in one form or another, such as blood, milk solids, oils and grease. Certain organic waste is also released from petrochemical industries, food and liquor industries and sewage works. Septic tanks are used for the disposal of sewage in many small communities.

CASE STUDY

The Jukskei River flows through Alexandra, which covers an area of over 800 ha and its infrastructure was designed for a population of about 70,000. Current population estimates vary widely and have been put at figures ranging from 180,000 to 750,000. The significant, unplanned population has overloaded the infrastructure such that water pressures are low and sewers frequently block and overflow. Maintenance of such systems is very difficult because the high densities and congested nature of the backyard shack development, making access for maintenance very difficult or impossible in places.

Illegal dumping of waste (mostly construction rubble, trolleys, dead animals and garden refuse) into the river occurs along the banks of the Jukskei in the Alexandra area. Some of these waste types are not generated in Alexandra implying that people from surrounding areas are responsible for illegal dumping within Alexandra. In Alexandra, grey water, putrescent waste, medical waste and domestic waste is dumped into the stormwater drains, which transports the waste to the river. Animals are slaughtered along the banks of the river, which results in blood and animal organs being dumped along the river banks.

Refer to **Figures H.3** and **H.4**, depicting scenes in Alexandra.

CASE STUDY (continued)

Figure H.3: **Informal settlements next to the Jukskei River**

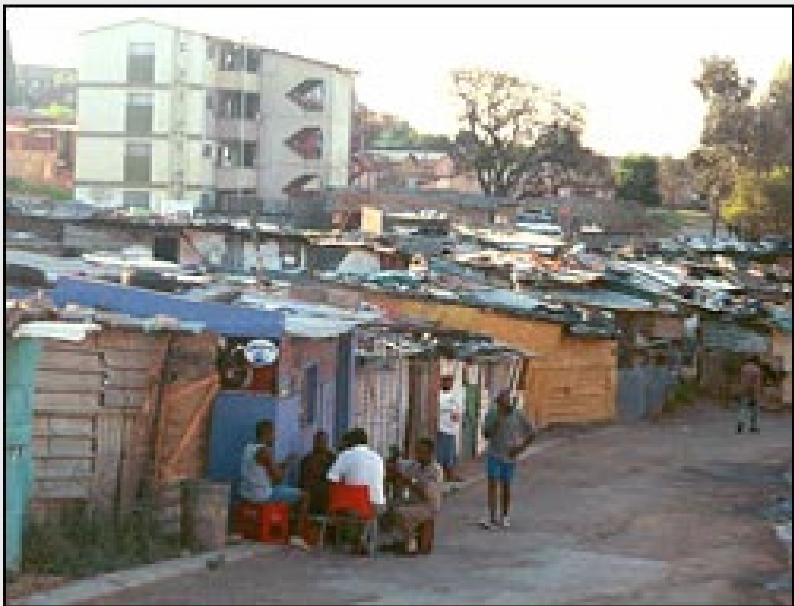


Figure H.4: **High density population in Alexandra (City of Johannesburg, 2002)**

Organic waste can also be generated from landfills if they are not properly planned or designed. Water percolating through landfills produces leachate, which may contain undesirable or toxic chemicals. Modern sanitary landfills are constructed to prevent leachate contamination of groundwater or surface waters. The bottom of the landfill is lined with impermeable layers, and the leachate is collected via a system of pipes and treated (onsite or at a waste water treatment plant) before being released to the environment.

In many developing countries landfills are old or illegal and not regulated, most are also reaching their capacity. These old landfills often do not have leachate management systems to prevent leachate pollution of the groundwater or surface water systems.

c) <u>Inorganic Waste:</u>

Inorganic wastes include effluents from industries and mines, which contains heavy metals and acidifying substances. Inorganic substances like ammonia, nitrate and phosphates are sourced from agricultural activities and human settlements.

CASE STUDY
The Russell Stream, which forms part of the Klipspruit Catchment, flows through an industrial section that comprises of mines (refer to **Figure H.5**). Large quantities of silt and sand (containing inorganic compounds) are deposited in the stream. Severe silt deposition exists in the area between Nasrec Road and New Canada Road.

CASE STUDY (continued)

Figure H.5: Siltation in the Russell Stream (JDA, 2002)

d) Summary:

Table H.1 provides a summary of the various forms of pollution (i.e. waste types) and what land use they originate from.

Table H.1: Pollutants from urban land uses (adopted from Government of Western Australia, 1997)

Land use	Pollution Pathways	Potential Pollutants
Urban	o Stormwater drainage (pipes, drains and watercourses) o Runoff from roads, parks and gardens	o Nutrients (fertilisers) o Pathogens (bacteria and viruses) o Fuel and oil from vehicles o Tyre rubber o Heavy metals (e.g. lead from petrol, chromium, cadmium) o Pesticides/herbicides o Litter (e.g. paper, plastic, bottles, cardboard, aluminium cans) o Sediments o Colour (tannins)

Table H.1: (continued)

Land use	Pollution Pathways	Potential Pollutants
Urban	o Groundwater from areas with septic tanks o Sewage effluent	o Nutrients o Chemicals (e.g. fats, soap, detergents, solvents, disinfectants, grease) o Pathogens (bacteria and viruses)
Urban	o Groundwater (leachate) and surface runoff from sanitary landfill and liquid waste disposal sites	o Nutrients o Bacteria, especially Salmonella (spread by scavenging birds, rodents and insects) o Toxic substances depending on nature of wastes o Acids and alkalis
Urban	o Runoff from foreshore recreation areas and marinas, bilge and ballast water from watercraft.	o Litter o Nutrients (fertilisers and watercraft discharges) o Pathogens (bacteria and viruses) o Oil and hazardous chemicals in bilge water o Heavy metals (anti-fouling paint) o Oil and petrol (e.g. from boat exhausts)
Industry	o Industrial waste discharges o Accidental spills o Runoff and groundwater from industrial areas	o Nutrients o Chemicals depending on industrial process (e.g. acids, alkalis, heavy metals, oil, solvent, organic chemicals) o Heated water

Table H.1: **(continued)**

Land use	Pollution Pathways	Potential Pollutants
Agriculture and Horticulture	o Runoff, water from agricultural drains, groundwater	o Nutrients (fertilisers and animal wastes) o Sediment (from soil erosion) o Bacteria o Heavy metals o Pesticides (herbicides, fungicides, insecticides) o Salt
Forestry	o Runoff and groundwater	o Herbicides and pesticides o Sediment
Mining	o Runoff from mined areas, refuse heaps and tailing ponds o Mine process or cooling water	o Sediment o Acid and alkaline waste o Toxic substances depending on process (e.g. heavy metals, cyanide, oil, solvents).

1.2.2. Effects

a) Physical Waste:

Silt and foam from industries are visible and make the water unsuitable for recreational purposes (Department of Environmental Affairs, 1990). The detrimental effects of sediment include interference with the spawning of fish by covering the gravel beds; interference with light penetration, thus making food more difficult to find; and direct damage to the gill structures (Vesilind and Pierce, 1983). Settling out of the suspended solids may smother aquatic plants and animals leading to the retardation of benthic activities. The sediments may also reduce the clarity of the water, so that birds cannot see their underwater prey. The clarity in the water will also restrict the light availability of aquatic plants.

Other undissolved solid substances like plastics take hundreds of years to biodegrade and can kill birds and fish which accidentally eat it or become entangled. In the aquatic and marine environment plastic bag litter is lethal, killing at least 100,000 birds (refer to **Figure H.6**), whales, seals and turtles every year. After an animal is killed by plastic bags its body decomposes and the plastic is released back into the environment where it can kill again (Planet Ark, 2004).

Figure H.6: **Plastic bags and birdlife (Planet Ark, 2004)**

CASE STUDY
The predominant waste type in the Jukskei River is dependent on the land use along the river. The Jukskei is a unique urban river in that it flows not only through different development areas such as industrial, residential and commercial but within each development zone are different economic groups. For instance, the impact of waste in the Bruma area is completely different to the impact of waste in Alexandra, even though both areas are considered residential areas. Hence, it is not possible to quantify the impact of waste on the Jukskei River in a holistic manner without giving specific attention to the nature of the development along the banks of the river. Litter is the most predominate waste type encountered along the Upper Jukskei. The volumes of litter in the river vary with the land development use and the socio-economic conditions of each type of land use.

b) Organic Waste:

The major effect that organic pollutants have on the aquatic system is the depletion of the store of the dissolved oxygen in the water due to the numerous oxidation reactions taking place. The organic pollutants are mainly oxidised by means of various bacteria in the water (Campbell, 2001).

The excess phosphates and nitrates in the water mean that these nutrients accumulate in the water, which results in organic material being produced in abundance. This process is called eutrophication. An euthrophic waterbody is highly productive in organic material and can result in algal blooms (refer to **Figure H.7b**) which are short lived and whose decay imposes a heavy oxygen demand on the water (Porteous, 1992). Algal blooms often occur during summer when warmth and light stimulate growth (Government of Western Australia, 1997).

Bacteria from human and animal waste cause diseases such as cholera, typhoid, paratyphoid, bacillary dysentery, etc. Protozoa causes amoebic dysentery, while worms cause illness such as bilharzia. Viruses cause a range of diseases like eye infections, gastro-enteritis and hepatitis. Pesticides such as DDT can also increase the risks of birth defects and are proven carcinogens.

Other organic contaminants like pesticides are not easily broken down and are toxic to the fish. These types of pollutants have an accumulative and lasting effect.

Contaminants like oils form a surface layer over the water causing a lower rate of reiteration, which adversely affects the respiration of aquatic biota.

Figure H.7: **Algal Bloom in the Schuykill River, Philadelphia, USA (www.urbanrivers.org)**

CASE STUDY

In Kliptown, most of the informal settlements are without proper sewer network connections, resulting in sewage pollution of the Klipspruit. Currently Johannesburg Development Agency is developing Kliptown as part of the Blue IQ project. Proper sewerage and stormwater systems are expected to be in place by the end 2006.

Figure H.8: **Sewerage pollution from discharging sewer pipeline in Kliptown into Klipspruit**

c) Inorganic Waste:

Inorganic pollution is much more difficult to control and potentially more hazardous than organic pollution. Certain inorganic substances, such as those used by chemical industries, are extremely toxic and may destroy aquatic life completely (Department of Environmental Affairs, 1990). Most of the heavy metals are chemically inert and are transported downstream with equilibrium between the ions in the benthic layer and the ones in the river water. They are conservative ions, the mass of the pollutant is not altered by the chemical and biological processes occurring in the surface water and once they enter the river, they may be diluted or dispersed but not changed in quantity (Campbell, 2001). However at certain pHs, the valence of the metals is changed allowing it to harm aquatic life.

The inorganic ions also cause turbidity, which leads to deterioration in light transmissivity. Activity and growth of aquatic plants are inhibited even to the extent of complete elimination. Some inorganic contaminants such as sulphurous acid exert an oxygen demand, as oxygen in the water is used for the oxidation of the sulphurous acid to sulphuric acid. The most notorious impact associated with mining is the occurrence of Acid Mine Drainage (AMD), i.e. the process whereby pyrite (FeS_2), is oxidised to create sulphuric acid. Leaching of metals is further accelerated through low pH conditions induced by AMD. Surface drainage delivers AMD by-products to the nearby river, causing acidic conditions and an accruement of metal ion concentrations and suspended solids.

Some toxins, including heavy metals (such as lead, copper, mercury) and some chemicals build up in the sediments. They can be taken up by plants or animals over a period of time and passed through the food chain without causing obvious ill effects. Symptoms such as lesions (skin damage) on fish, thinning of birds' egg shells, or birth defects, appear as the level of the toxin in their fat tissue and can become poisonous if eaten by animals or people (Government of Western Australia, 1997).

Case Study

Various tributaries of the Klipspruit (including the Russell Stream and Bosmont Spruit) are silted with waste sand from mining operations. Gold mining has lead to the deposition of substantial quantities of silt in the stream channels, choking the river systems. An apparent problem in the catchment is the proximity of numerous tailings dams to watercourses.

An examination of the Klipspruit lead to the finding of leaking slimes delivery pipelines. These pipelines cover vast, isolated areas, and without regular maintenance and inspection similar discharges will persist, acting as a constant pollution source.

Mining-related effects have added considerably to the overall reduction in the ecological integrity of the Klipspruit. Not only has the aquatic biota been adversely affected, but also the riparian area (with the associated fauna and flora species) has suffered marked impoverishment.

AMD is also apparent in this catchment, the familiar rust colour from iron precipitation, commonly referred to as "yellow boy", further detracts from the scenic value of the catchment. Mining problems persist in the downstream direction for a substantial distance. The Bosmont Spruit appears to have borne the main brunt of the mining legacy, with a sterile freshwater environment along the mining grounds, as shown in **Figure H.9**.

Figure H.9: Bosmont Spruit traversing mining grounds

1.3. Assessment and Management of Waste in an Urban Catchment

1.3.1. Assessment Tools

a) <u>Volume of Litter:</u>

The volume of litter conveyed by urban catchments was assessed by Armitage *et al.* (2001) who indicate that various independent factors influence the rate of litter production, including:

- Type of development (e.g. commercial, industrial or residential);
- Density of development;
- Income level of the community (poor people in poor countries do not waste as much as more affluent societies);
- Type of Industry (some industries produce more pollutants than others);
- Rainfall patterns (storms tend to sweep litter into drains, whereas in a dry area litter would remain until picked up by the local authority);
- Type of vegetation in the catchment (leaves are a major source of litter with some trees being more problematic than others);
- Efficiency of refuse removal by local authority (sweepers themselves may be a problem when they sweep or flush the litter into the stormwater drains);
- Level of environmental concern of the community (some active communities have been known to stop companies from using for example polystyrene containers); and
- The extent of legislation (this would prohibit or reduce waste). Two associated factors would be the effectiveness of the policing of the legislation, and the level of fines.

Hence, it is understood that ***each catchment has a unique litter "footprint" which is indicative of the state of the catchment at the time of measurement*** (JDA, 2002*).*

The following formula is suggested in calculating the total litter loading. This is considered a preliminary guide to design, which although highly hypothetical, is tentatively suggested by the authors until such time that better data is available (Armitage *et al.*, 2001):

$$\mathbf{T = \sum f_{sci} \bullet (V_i + B_i) \bullet A_i}$$

where	T	=	Total litter load in the waterways (m^3/year)
	f_{sci}	=	Street Cleaning Factor
	V_i	=	Vegetation load for each land use
	B_i	=	Basic litter load for each land use
	A_i	=	Area of each land use (ha)

CASE STUDY
Pikitup maintains records on volumes of waste collected within the City of Johannesburg and the Gauteng Department of Agriculture, Conservation and Environment (GDACE) maintain records of the volumes of waste disposed of on most landfill sites in Gauteng. According to City of Johannesburg (2002), the Johannesburg Roads Agency (JRA) is in the process of auditing the stormwater systems in Johannesburg. This information will assist in quantifying the litter load in the stormwater system at a later stage. No information exists on the tonnages of waste entering the informal waste stream. The theory is that more that fifty percent of the waste in the informal waste stream makes its way to the Jukskei River (City of Johannesburg, 2002).

b) <u>Chemical and Physical Monitoring:</u>

A measure of organic waste load is biochemical oxygen demand (BOD), which indicates the amount of oxygen drawn upon in the process of decomposition of the waste. Some of the other common measures of water quality are chemical oxygen demand (COD), alkalinity, acidity, colour, hardness, taste, odour, turbidity and electrical conductance (Kneese and Bower, 1968). Further elaboration on chemical and physical monitoring is provided in **Section C** (**Water Quality**).

c) <u>Biological Monitoring:</u>

The River Health Programme (RHP) consists of partnerships that are critical for the success of the programme. At the national level, the DWAF plays the lead role while the Department of Environmental Affairs and Tourism (DEAT) and the WRC are key partners. At provincial level, each province has a network of implementers who work together, usually under the leadership of a Provincial Champion.

The RHP primarily makes use of biological indicators (e.g. fish communities, riparian vegetation, aquatic invertebrate fauna) to assess the condition or health of river systems. The rationale for using biological monitoring is that the integrity of biota inhabiting river ecosystems provides a direct, holistic and integrated measure of the integrity or health of the river as a whole

SASS5 is a scoring system/biotic index based on benthic macroinvertebrates, whereby each taxon (i.e. invertebrate family) is allocated a sensitivity/tolerance score according to their susceptibility to changes in water quality conditions.

Benthic macroinvertebrates not only differ in their sensitivity/tolerances to different pollutants, but also in their habitat preferences. Hence, for a bioassessment to obtain results that adequately reflect the true condition of a particular stream or river, a habitat assessment needs to be performed. The Invertebrate Habitat Assessment System (IHAS) was developed to incorporate habitat variability as an influencing factor in deriving SASS5 scores.

Further elaboration on biological monitoring is provided in the deliverable on **Water Quality**

1.4. Management Considerations

1.4.1. Legal Framework

The following is an excerpt from the Integrated Waste Management Strategy (DEAT & DWAF, 1997) that includes some framework legislation with regard to waste management in the country:

a) The Constitution of the Republic of South Africa, 1996 (Act 108 1996)

All legislation has to fall within the stipulations of the Constitution. The following sections are of particular relevance:

- *Section 24* – The right to a clean and healthy environment
- *Section 32* - Access to information
- *Section 33* - Just administrative action
- *Chapter 6* - Provincial Government competency (Schedules 4 & 5)
- *Chapter 7* - Local Government competency (Schedule 4 & 5)

b) The National Environmental Management Act, 1998 (Act 107 of 1998)

This Act provides for co-operative environmental governance by establishing principles for decision making on matters affecting the environment. As the principal framework act for environmental issues, it has direct relevance to the implementation of the National Waste Management Strategy (NWMS), one of the key implications being the designation of DEAT as lead agent for the environment. In the NWMS specific roles have been identified for the National Environmental Advisory Forum and for the Committee for Environmental Co-ordination, while provision has also been made for using Environmental Implementation and Management Plans, and Environmental Management Co-operation Agreements. Chapter 7 of NEMA also has important direct implications for the achievement of the NWMS initiatives.

c) The Environment Conservation Act, 1989 (Act 74 of 1983)

Section 20 of this Act, which deals with waste management, provides for the permitting and related control measures for the operation of waste landfill sites, which must be administered by DWAF. However the Amendment Bill has transferred the administration of this provision of the Act to the Minister of Environmental Affairs and Tourism.

d) The National Water Act, 1998 (Act 36 of 1998)

The purpose of the Act is to ensure that the country's water resources are protected, used, developed and conserved in ways which take into account the protection of aquatic and associated ecosystems; that addresses basic human needs; that ensures the reduction and prevention of pollution; and that meets international obligations. Relevant sections to waste management include:

- *Section 20* - control of emergency incidents
- *Section 21(g)&(h)* - water use includes disposing of waste in a manner, which may detrimentally impact on a waste resource.
- *Section 138* – Establishment of National Information System

e) The Atmospheric Pollution Prevention Act, 1965 (Act 45 of 1965)

This Act, administered by DEAT, regulates the control of air pollution. In terms of Schedule 2 "waste incineration processes" is deemed to be a scheduled process thus requiring a registration certificate. Regulations may be promulgated in terms of section 44 of the Act.

f) The Minerals Act, 1991 (Act 50 of 1991)

This Act is administered by the Department of Minerals and Energy (DME) in close consultation with DWAF, DEAT, the Department of Health and the Department of Agriculture as stipulated under section 39(3)(b). Section 39, relating to Environmental Management Programme Reports (EMPRs), is of particular relevance.

g) The Hazardous Substances Act 1973 (Act 15 of 1973)

This Act (and its regulations) controls the transportation of defined hazardous substances and prohibits the disposal of certain radioactive wastes on landfills.

h) The Health Act, 1977 (Act No 63 of 1977)

This Act is used by DWAF to determine the buffer zone of a proposed waste disposal site.

i) The Nuclear Energy Act, 1993 (Act 131 of 1993)

This Act is administered by the Council for Nuclear Safety and is referred to in the Minimum Requirements (DWAF) for the classification of wastes. The Act is of specific relevance to the development of the strategy for radioactive waste.

j) The Local Government Transition Act (Act 209 of 1993)

This Act makes provision for the powers and duties of local authorities (schedule 2 & 2(a)). In terms of the Act local councils must formulate and implement an integrated development plan incorporating land use and infrastructure planning. This development planning could include the determination of a waste disposal strategy and the identification of sites for waste disposal facilities.

k) The Organised Local Government Act (Act 52 of 1997)

This Act provides for procedures by which local government may consult with the national and provincial governments and is of relevance to some of the NWMS planning initiatives.

l) Import and Export Act 45 of 1963

Section 2 (1) of the Act may be used to regulate the import and export of waste.

1.4.2. Waste Management Principles

The following principles have been implemented by DWAF for the Control of Waste (DWAF, 1998):

- ***Cradle-to-grave***: A policy of controlling waste from its creation (cradle) to its disposal (grave).
- ***Duty of Care Principle:*** The individual or organisation that produces the waste (the Generator) is under all circumstances, responsible for that waste from cradle-to-grave.
- ***Integrated Waste Management:*** An internationally accepted four-step approach used to manage waste.
- ***Polluter Pays Principle:*** The person who causes pollution must pay for it's clean up and for any damages caused.
- ***Precautionary Principle:*** Unknown waste must be treated as extremely hazardous until it is identified and classified.

1.4.3. Managing Waste from Dense Settlements

DWAF has long recognised that pollution from densely populated, and poorly serviced areas, is one of the greatest threats to the quality of South Africa's water resources. In this regard, DWAF have undertaken a comprehensive study on managing the water quality of dense settlements, and have produced various documents that detail aspects that should be considered in confronting this vast problem (DWAF, 2001).

Topics discussed include:

- Planning to avoid pollution problems;
- Summaries of experiences in tests cases;
- The economic impact of pollution; and
- Legal considerations in managing pollution from dense settlements.

The test cases were carried out in areas throughout South Africa to assess the variety of problems encountered and the way forward. Kliptown was one of the test cases.

1.4.4. Management Tools

The following tools can be recruited in managing waste-related impacts to urban rivers:

a) **National Waste Management Strategies and Action Plans in South Africa** (Waste Minimisation and Recycling Team, 1999) –
The project for the development of a National Waste Management Strategy (NWMS) for South Africa was initiated during 1997 by DEAT and DWAF, with financial support from the Danish Co-operation for Environment and Development (DANCED). The overall objective of the NWMS is to reduce the generation and environmental impact of all forms of waste and to ensure that the health of people and the quality of the environmental resources are no longer affected by uncontrolled and uncoordinated waste management.

b) **Catchment Management Strategy (CMS) (Biswas, 2003) –**
South Africa has taken the initiative for formulating a Catchment Management Strategy (CMS) for each Water Management Area (WMA) in the country. The CMS is a process for integrating environmental, economic and social considerations in management of catchment areas. Included in the issues that will be addressed by the CMS is water quality status and pollution control requirements.

c) **State of the Environment (SoE) Reporting –**
State of the Environment (SoE) reporting, led by DEAT, has developed over the past decade in response to a need for appropriate information to assist with

environmental decision making. The national SoE for South Africa uses the Driving Force-Pressure-State-Impact-Response framework to explain what is causing environmental change, how good of the bad conditions are and what we can and are doing about it.

d) Integrated Waste Management

Integrated Waste Management is a vital requirement in maintaining and preserving the country's water resources. According to DWAF (1998), waste is managed in four steps:

Step 1: Industries should use processes that make the least possible waste – i.e. ***Cleaner Technology***.

Step 2: Anything that can be used again should be taken out of the waste – i.e. ***Resource Recovery***.

Step 3: Some waste can be ***compacted*** to take up less space, and ***treated*** so that it is less dangerous.

Step 4: All waste remaining after steps 1 to 3 must go to a properly designed and operated landfill (***Sanitary Landfill***)

The first three steps are not yet enforced. In future, however, the NWMS will control these activities. This strategy will make sure that waste is controlled from its creation to its disposal (i.e. cradle-to-grave principle).

Waste may be only disposed of at a permitted landfill. To set standards and help with issuing of permits, DWAF published a Waste Management Series, which comprises of the following documents:

- Minimum Requirements for Handling, Classification and Disposal of Hazardous Waste;
- Minimum Requirements for Waste Disposal by Landfill; and
- Minimum Requirements for the Monitoring of Water Quality at Waste Management Facilities.

The third edition of the abovementioned Minimum Requirements was published in 2005 by DWAF.

e) Litter Traps

Litter traps are only considered effective if they are properly designed and regularly maintained (i.e. cleaned). In order to achieve an accurate design the designer would need to know the type and volume of litter entering the stormwater system. This is achieved through a detailed litter survey of the catchment and by determining the litter load of the waterways.

According to Armitage *et al.* (2001), the ideal trap should have the following features:

- Economical to construct and operate;
- Simple operation;
- No moving parts;
- Should not require an external power source;
- Robust;
- Able to handle widely varying flow-rates;
- High removal efficiency;
- Never block;
- Reliable;
- Safe;
- Should not constitute a health hazard (e.g. by providing a breeding spot for mosquitoes and flies);
- Should not increase the flood hazard in the vicinity of the structure (it must not cause substantial damming of the water);
- Minimal maintenance;
- Minimal water head (it can be used in association with flat gradients);
- Easy to clean, e.g. by collecting all the litter in a central point for removal by the local authority; and
- Unattractive to vandals.

All these conditions are almost impossible to meet; therefore it is imperative that the litter problem be addressed at the source.

I. GUIDELINE TO DEVELOP A SUSTAINABLE URBAN RIVER MANAGEMENT PLAN

1. INTRODUCTION

The SURMP offers an approach to managing an urban river by packaging catchment information and available assessment and management techniques into a toolbox for easy use by the guideline user (refer to **Intended Audience** in **Section 3**).

Thorough knowledge of an urban catchment is the starting point and an essential prerequisite to efficient and suitable management efforts. Such knowledge includes the delineation of the catchment boundaries, detailing of the physical, chemical, biological and socio-economic character of the urban river and understanding the inherent problems within the catchment. The process of understanding the urban river forms a vital component of the SURMP.

A number of management techniques and tools for rivers have been created by national and regional authorities, municipalities, educational and research institutions, private sector, etc. Although the functions of these tools may vary, depending on the intention and specific aspect of the river to be managed, they offer a sound knowledge base for creating the SURMP.

The framework of the SURMP will be presented in this document, and the necessary guidance will be provided for the completion of the various sections of the plan.

2. SUPPORTING DOCUMENTS

Various informative sections (**Section B – H**) precede the final guideline document. The function of these sections is to act as supporting documentation for the guideline, and they focus on some of the primary features which influence the state of urban rivers.

3. INTENDED AUDIENCE

In a broad sense, any parties charged with the management of urban rivers may employ the guideline document to generate a SURMP.

The main focus group of the guideline is however municipalities, more specifically those municipal departments tasked with overseeing urban catchments within their jurisdiction.

It is accepted that the guideline user will have some level of competency with regard to river assessment and management. Nevertheless, the supporting documents endeavour to familiarise the user with some key aspects surrounding urban rivers. The guideline to develop a SURMP also aims to be a user-friendly instrument that allows for the compilation of a comprehensive plan through sound guidance. It is important to note that the completion of the SURMP may require a multidisciplinary team, where the various elements of the urban river need to be addressed in a competent manner.

Under the Water Services Act (WSA) (No. 108 of 1997), municipalities and councils are Water Services Authorities and are mandated to ensure access to water for all within their jurisdiction. Primary water resource management is vested in DWAF and Catchment Management Agencies (CMAs) on a national and Water Management Area (WMA) scale, respectively. Participative management of water resources is however supported by various water resource management policies, which provide the opportunity for municipalities and other interest groups to proactively partake in the management of watercourses on a local-scale. The SURMP can be produced by municipalities to fulfil this role.

4. AIMS OF THE GUIDELINE

The aims of the guideline to develop a SURMP are as follows:

- To assist practitioners in the urban river field to generate a plan for the sustainable management of urban rivers;

- To articulate a consistent municipal approach to urban river management; and
- To promote conformity in urban river management under local authorities.

5. METHODOLOGY

As part of the methodology undertaken to prepare this guideline, the following key tasks were performed:

- Perusal of past documentation on local and global catchment management;
- Interviews with members of the City of Johannesburg Municipality and the Department of Water Affairs and Forestry (DWAF); and
- Using experience and lessons learnt from the preparation and implementation of the Jukskei River Environmental Management Framework (City of Johannesburg, 2002).

6. ASSUMPTIONS AND LIMITATIONS

The following assumptions and limitations apply:

- The SURMP cannot possibly account for every particular circumstance that may be encountered. The guideline user may need to incorporate additional measures to address specific assessment and management needs.
- Consideration must be given to the extent to which these guidelines are realistically achievable given the resources available to those charged with the development and implementation of the SURMP.
- An exercise of judgement is required by the guideline user when developing the SURMP. Based on the intention of the SURMP and the urban river in question, only certain parts of the SURMP may be applicable (e.g. characterisation and assessment of only the pertinent attributes of the urban watercourse).

7. GUIDELINE OUTLINE

A guideline is seen as a principle or criterion that guides or directs action, which in this instance is the development of a SURMP. The guideline grants specific orientation to enable the completion of the various sections of the SURMP.

When developing a SURMP there are five main elements that need to be examined, namely:

6. The **general details** of the urban river;
7. The **character** of the urban river;
8. The **pressures** associated with the urban river;
9. The **values** of the urban river; and
10. The **management** of the urban river.

Appendix A provides the content page for the SURMP, which grants direction to this guideline. It should be noted that, depending on the management requirements and the character of the urban river in question, the contents page could be adjusted to meet the needs of the SURMP developer.

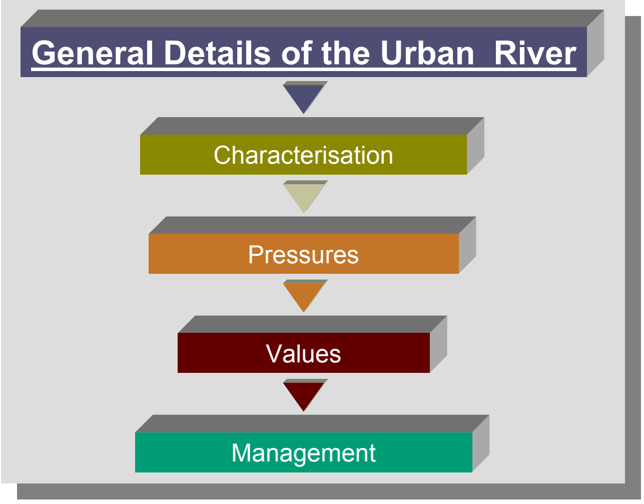
8. GUIDING THE COMPILATION OF THE SURMP

The guideline will hereafter lead the user through the various components of the SURMP, by introducing the sections and their purpose to the user, and providing direction on the completion of these sections. The guideline will thus navigate the user through the contents page of the SURMP, as provided in **Appendix A**. During this process each section of the SURMP will be discussed by using the following symbols:

🗣	Comment on general information and the purpose and relevance of the section.
!	Description of task(s) to be performed for completion of section.
🛠	Techniques and methods available.
ⓘ	Information sources that may be utilised during the execution of the tasks. Note: **Past reports** refer to documentation of past studies that included the specific attribute in question. **Guidelines** refer to documented guidelines that include the specific attribute in question. **Interest groups** refer to parties with a particular interest in and/or knowledge of the attribute in question.

Although the order, tasks and concomitant information sources are provided, the manner in which the sections are to be presented and information is to be displayed is omitted. This is to encourage the SURMP developer to use a combination of experience and initiative during the compilation of the plan. Despite the freedom provided, the information must nonetheless be presented in a meaningful and scientifically acceptable manner.

1. INTRODUCTION TO THE URBAN RIVER



This section introduces the urban river that is to be managed by providing general details. The SURMP developer will most probably be familiar with the urban river to be assessed and managed. If this is not the case the steps followed during the completion of this section and the subsequent sections will acquaint the guideline user with the urban river in question.

It is important to decide on the exact portion of the urban river for which the SURMP is to be prepared. Based on the intention of the SURMP, the subject area may encompass the entire urban river or only a stretch of the watercourse. Additional decisive factors in this regard include the availability of the necessary resources, time-constraints, and urgency of and need for the SURMP. Management efforts will however need to be attentive to what is occurring upstream and downstream of the selected area.

1.1 Urban River Description

As a point of departure, a general overview of the urban river is prepared.

!	🛠	ⓘ
Include information on the following:		
Name of the urban river	1. Research	1. Maps • Topographical map 2. Past reports
Geographical description Describe the location of the urban river with regard to a city, town and suburb(s). Provide a map of the urban river and its catchment.	1. Site survey	1. GIS 2. Maps • Topographical map
Source of the Urban River Mention the source of the watercourse and the general route of its headwaters.	1. Site survey	1. Maps 2. Past reports
	2. Request information	1. DWAF[1] 2. Interest groups
Catchment description Name the Water Management Area (WMA) and catchment (at least quaternary). Provide a map indicating the catchment boundaries.	1. Request information	1. DWAF
	2. Research	1. Map[2]
Land use Identify the existing land use types within the study area's catchment.	1 Research	1. Past reports
	2 Site survey	1. Map 2. Municipal Town Planning Department
Identify future land use types within the study area's catchment.	1. Research	1. Regional Spatial Development Framework (RSDF)

[1] www.dwaf.gov.za/ContactRegions.htm

[2] DWAF. 2000. Water Management Areas of the Republic of South Africa. DWAF, Pretoria.

1.2 Water Users

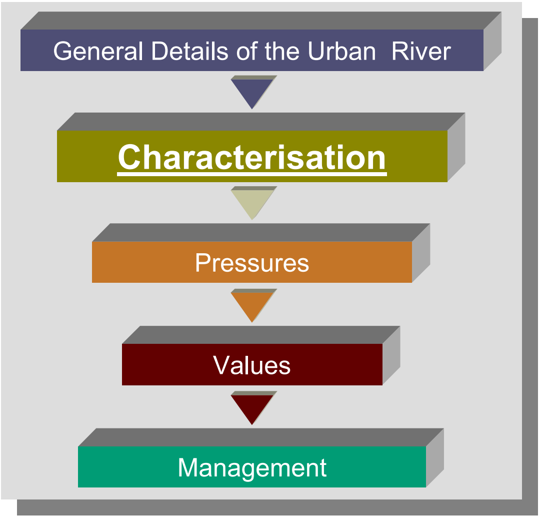
Section 21 of the National Water Act (NWA) (No. 36 of 1998) lists eleven water use types. The relevance of discussing the particular water users of the urban river, in the SURMP, stems from the interaction of these uses with the water environment and vice versa, as well as the importance that is placed on the urban river by the water users. Water users have a certain expectancy of the urban river and their demands must be met in a sustainable manner. This becomes pertinent in the management component of the SURMP where the safeguarding and enhancement of the goods and services of the urban river come to the fore.

Water users may be compatible or non-compatible with each other, based on the needs of the users and the effects to the receiving water environment. These interdependencies have to be established early on in the development of the SURMP.

!		
Determine and list the various water users of the urban river. Include information of the locality, water user particulars, water quantity and/or quality requirements, and authorisation status.	1. Request information	1. DWAF[3]

[3] www.dwaf.gov.za/ContactRegions.htm

2. URBAN RIVER PROFILE



Before managing an urban river, thorough knowledge of the river's attributes (bio-physical, socio-economic and built environment) and their condition is required. This process is referred to as profiling/characterisation of the urban river, and entails the acquisition and interpretation of information.

Characterisation allows for conclusions to be drawn with regard to the urban river's status in terms of its integrity/quality and the pressures/problems/issues that are present. This sets the scene for ensuing management actions.

DWAF has prepared a guide to conduct a Catchment Assessment Study (CAS) from a water quality perspective[4]. The characterisation phase of the SURMP hold similarities to a CAS (process also known as a Situation Assessment), however the last mentioned focuses strongly on water quality whereas the SURMP provides a more holistic profile of the urban river.

It is noted to the SURMP compiler that the assessments requested in the sections below should only be performed if deemed necessary to satisfy information needs for both characterisation and management of the urban river. Some studies may prove to be costly, and the information produced may not be required for immediate management endeavours.

[4]DWAF. 2003. Water Quality Management Series, Sub-Series No. MS 8.3. *A Guide to conduct Water Quality Catchment Assessment Studies: In support of the Water Quality Management Component of a Catchment Management Strategy*. Edition. DWAF, Pretoria.

2.1 Natural

The natural attributes of an urban river are divided into physical, chemical and biological elements.

2.1.1 Climate

The influence of climate on water resources is mainly associated with the rainfall and evaporation. Stream flow increases after rainfall events, and in an urban river context strong downpours produce significant runoff which often result in flood-related damage to the river structure and man-made structures located within the floodlines.

Evaporation lowers the water levels, as water is transformed from liquid to vapour. Evaporation rate is dependant on temperature, wind speed, humidity, atmospheric pressure and the surface to volume ratio of the water body.

Seasonal climatic conditions play a lead role in river flow fluctuations, depending on precipitation and evaporation rates.

!		
Provide data on the temperature, rainfall, evaporation and prevailing winds over a period of time. Manipulate data using statistical methods.	1. Request information	1. South African Weather Bureau[5]

[5] South African Weather Bureau - Tel: 082 233 8484

2.1.2 Topography

Major land features affect runoff rates, and the speed at which a river flows. In areas where the physical geography is steep, accelerated flows are expected. In contrast, where a river flows over relatively flat areas slower flow speeds occur. The surface features also dictate the shape and appearance of the catchment.

!	🛠	ⓘ
Discuss the topography of the urban river catchment. Mention major land features (e.g. ridges) and landscape units (e.g. alluvial floodplains).	1. Research	1. Past reports 2. Maps – • Topographical map

2.1.3 Geology and Soils

The major influence of geology and soil conditions on an urban river relate to the chemistry of the water.

Two important subdisciplines of geology are geomorphology and geohydrology. Geomorphology influences factors such as the channel type, substratum composition, and erosion potential. Geohydrology relates to the distribution and movement of groundwater

Changes in the geology and soil may lead to biotic differences in the urban river, and may also affect the vegetation type.

!	🛠	ⓘ
Discuss the geology and soil conditions underlying the urban river and its floodplain. Identify sensitive geological conditions.	1. Research	1. Past reports 2. Maps – • Geological maps 3. GIS
	2. Specialist study: • Geomorphological index • Geotechnical investigation	1 Specialist

2.1.4 Hydrology

Hydrology examines variables such as the amount and intensity of precipitation and the rate of flow in streams, thereby observing and predicting the reaction of water with its environment.

The hydrology of an urban river constitutes one the most important characteristics to be assesses and managed. The significance of hydrology and hydraulics (i.e. mechanics of water) surround the damage that is caused by urban rivers, especially following rainfall events.

The floodplain constitutes the low areas alongside a stream that is subjected to inundation during high flows. The frequency of the flooding of a floodplain is dependant on its relative elevation. A good measure of water resource protection includes maintaining the 100-year floodplain (i.e. the area of inundation that has a frequency of occurring, on average, once every 100 years) as a 'no-go' zone. The floodlines are calculated via hydrological modelling methods.

!		
Assess the hydrological conditions (i.e. catchment size, 1:50 year and 1:100 year floodlines, maximum annual peaks) of the study area	1. Research	1. Past reports
	2. Request information	1. DWAF[6] 2. Municipal Engineering Department
	3. Specialist study: • Hydrological index	1. Specialist
Provide localities of gauging stations.	1. Request information	1. DWAF

[6] DWAF Directorate: Hydrological Services – Tel: (012) 336 7500

2.1.5 Water Quality

A popular means of establishing the condition of a water resource is by testing the water quality. Water quality can be determined by assessing the physical, chemical and biological properties of water.

The water quality of a water resource determines its suitability for a particular use. This stems from the fact that water users often have variable water quality requirements.

Water quality is assessed by the recruitment of monitoring methods, which depend on the attribute of the water resource that is to be examined. The results from the monitoring activities are analysed and inferences are made regarding the state of the water resource, based on the water quality findings.

!		
Identify existing monitoring points and water quality data.	Research 2. Request information	Past reports 1. DWAF[7] 2. Resource Quality Services (RQS)[8] 3. Catchment Forums
Undertake water quality monitoring programme, comprising of the following tasks:		
a) Select strategic sampling points	1. Site survey	1. Map
b) Perform monitoring at sampling points.	1. Sampling techniques 2. Water quality indices	
c) Analyse for chemical-physical parameters that are associated with the type of land use, pollution sources and properties of the water that is considered important for the water users present.	1. Laboratory analysis	

[7] www.dwaf.gov.za/ContactRegions.htm

[8] Resource Quality Services - Tel: (012) 808 9500

d) Perform biomonitoring at the same sampling localities.	1. Biomonitoring indices (**SASS4, IHAS, FAII, RVI, IHI)**	1. Guideline[9]
	2. Specialist study	1. Specialist
e) Identify 'hotspots' (i.e. monitoring points with unacceptable value(s) for water quality variables)	1. Research	1. Guidelines[10] 2. Water Quality Objectives (if applicable)

[9] Mangold S. 2001. National Aquatic Ecosystem Biomonitoring Programme: An Implementation Manual for the River Health Programme – a hitch hiker' s guide to putting the RHP into action. NAEBP Report Series No 15. Institute for Water Quality Studies, DWAF, Pretoria.

[10] DWAF South African Water Quality Guidelines, Second Edition, 1996

2.1.6 Flora

The plant-life associated with watercourses includes the riparian and aquatic (/instream) vegetation.

The riparian zone is the area that borders the watercourse and the vegetation situated inside this zone serve numerous valuable functions, including the purification and retention of runoff, habitat provision, bank stabilisation and aesthetic quality. The encroachment of exotic vegetation threatens indigenous flora, with the potential loss of their beneficial properties. In addition, some exotic trees deplete groundwater resources through the extensive water uptake via their root systems.

Instream vegetation occurs within the flow of the watercourse. Important functions of instream vegetation include flow regulation, habitat provision, and water purification.

!	🛠	ⓘ
Identify aquatic and riparian vegetation.	1. Research	1. Past reports
	2. Site survey	
	3. Request information	1. Local botanical gardens 2. Interest groups
	4. Specialist study - Biomonitoring indices **(IHAS, RVI, IHI)**	1. Specialist
Identify sites with protected species.	1. Request information	1. Provincial Conservation Department 2. Interest groups
	2. Specialist study	1. Specialist
Identify 'hotpots' (i.e. sites with significant exotic encroachment).	1. Research	1. Past reports
	2. Site survey	
	3. Request information	1. Local botanical gardens 2. Interest groups
	4. Specialist study	1. Specialist

2.1.7 Fauna

The fauna that utilise urban watercourses can be divided into terrestrial and aquatic animal-life.

Terrestrial fauna in urban centres is commonly associated with those species that are tolerable to human influence. The open spaces alongside urban watercourses are used as corridors for animal movement. Floodplains further provide habitat and feeding opportunity.

The aquatic animal communities in urban waters are mostly impoverished, with poor diversity and an absence of sensitive species. Poor water quality and degraded habitat conditions are the primary contributing factors to this phenomenon.

!	🛠	ⓘ
Identify terrestrial fauna that occur in and alongside study area.	1. Research	1. Past reports
	2. Site survey	
	3. Request information	1. Interest groups
	4. Specialist study	1. Specialist
Identify areas where protected species occur	1. Request information	1. Provincial Conservation Department) 2. Interest groups
	2. Specialist study	1. Specialist
Identify aquatic fauna.	1. Request information	1. Resource Quality Services (RQS)[11]
	2. Biomonitoring indices (**SASS4, FAII**)	
	3. Specialist study	1. Specialist

[11] Resource Quality Services - Tel: (012) 808 9500

2.1.8 Wetlands

A wetland refers to an area which is "transitional between terrestrial and aquatic system where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil" (National Water Act, No. 36 of 1998).

The beneficial properties of wetlands are well documented. In an urban river context, wetlands *inter alia* store flood waters, dissipate flood energy, filter pollutants, stabilise the urban river structure (i.e. erosion protection), provide habitat and lend visual appeal. Unfortunately, urban wetlands are also associated with harbouring criminals, emitting foul odours and collecting refuse.

Some common impacts to wetlands include erosion, plug disruption, reduction in flow, pollution, siltation, invasive plants, burning, over-harvesting of reeds and encroaching structures (e.g. pipelines).

Locating and assessing wetlands within the study area of the SURMP provide the opportunity to generate management efforts to optimise the desirable functions of these systems and to eradicate impacts.

!		
Identify wetland(s) in study area.	1. Site survey	1. Maps – Topographical map
Evaluate identified wetlands (discuss noteworthy fauna and flora, soil description, land uses and impacts).	1. Research	1. Past reports
	2. Request information	1. Interest groups 2. Working for Wetlands (DWAF Initiative)[12]
	3. Specialist study	1. Specialist

[12] Working for Wetlands – Tel: (012) 336 7500

2.1.9 Estuaries

Estuaries are areas where fresh and salt water mix, at the mouth of a river. The importance of estuaries includes, amongst others, their ecological significance, use for recreational activities (e.g. fishing, boating), visual attraction, water purification ability, and nutrient cycling and supply function.

Estuaries are adversely affected by *inter alia* flow reductions, high sediment loads, poor water quality, encroaching structures, dredging, over-harvesting of natural resources, and peripheral development.

As natural assets, the SURMP should aim to maintain the valuable services offered by estuaries, and eliminate the negative impacts.

!		
Prepare map of estuary		
Discuss the following: • size and mouth condition; • water quality (suitability for aquatic life, suitability for human contact, trophic status); • aesthetic state; and • biological health.	1. Site survey	
	2. Research	1. Past reports 2. Guidelines[13][14]
	3. Request information	1. Interest groups
	4. Specialist study	1. Specialist
	5. Estuarine Health Index	1. Qualified person

[13] Breen C. M., & McKenzie M. 2001. Managing estuaries in South Africa: An Introduction. Institute of Natural Resources, Pietermaritzburg.
[14] Hay D. & McKenzie M. 2005. Managing Estuaries in South Africa: A Step by Step Guide. Water Research Commission, Pretoria.

2.2 Socio-Economic

An urban river is not only characterised by its natural attributes. By definition, an urban area encompasses a high density of people, who interact with the surrounding environment. This creates a strong social and economic backdrop to urban rivers that demand the integration of these attributes into the SURMP.

2.2.1 Public Perceptions

Input from the public is invaluable during the preparation of the SURMP. Sustainable management of urban rivers relies heavily on community participation, buy-in and stewardship.

The public may provide an historical perspective of the urban river, where they are familiar with the past conditions of the watercourse. They also provide insight into the problems experienced along the urban river, and their desires with regard to the river's future state.

Objectives of engaging the public, as part of the preparation of the SURMP, may include all or a combination of the following:

- Ascertaining public values and requirements;
- Ascertaining public concerns and issues; and
- Generating public collaboration and involvement opportunities.

!		
Undertake public participation, taking into consideration the pre-determined objectives.	1. Research	1. Past reports 2. Guidelines[15]
	2. Request information	1. Interest groups
	3. Public participation methods (e.g. advertisements, posters, public meetings and flyers	

[15]DWAF. 2001. Generic Public Participation Guidelines. DWAF, Pretoria.

2.2.2 Heritage Resources

Heritage resources refer to places or objects of cultural significance (i.e. aesthetic, architectural, historical, scientific, social, spiritual, linguistic or technological value or significance), in accordance with the National Heritage Resources Act (No. 25 of 1999).

Where heritage resources are at risk of damage from urban rivers or where they may be affected by any management activities, suitable mitigation measures are required.

!	🛠	ⓘ
Identify heritage resource situated in proximity to the urban river, and discuss heritage status.	1. Site survey	
	2. Research	1. Past reports
	3. Request information	1. Interest groups 2. South African Heritage Resource Agency (SAHRA)
	4. Specialist study	4. Specialist

2.2.3 Public Health

Urban rivers may pose a risk to public health in the form of physical safety (e.g. drowning, poor water quality) and personal safety (e.g. criminal activities in adjoining open spaces). Appreciation of the health and safety issues will inform management efforts.

!	🛠	ⓘ
- List the public health and safety risks associated with the urban river. - Provide 'hotspots' of physical and personal safety (where applicable). - Discuss existing control mechanisms (e.g. warning signage).	1. Research 2. Request information 3. Site survey	1. Municipal Department of Health 2. South African Police Service

2.2.4 Dense Settlements

Dense settlements are poorly serviced, with an absence of or inadequate water and sanitation, waste, and electrical services.). These areas often cause significant impacts to urban watercourses. Inhabitants of these settlements are also at risk of health and safety issues relating to the urban waters.

Where dense settlements occur in the urban catchment, management measures must be attentive to the control of the adverse affects linked to these areas.

!	🛠	ⓘ
Identify dense settlements located within the study area's catchment and discuss problems.	1. Survey	
	2. Research	1. Guidelines[16]
	3. Request information	1. Municipal Department of Public Health 2. Municipal Department of Housing

2.2.5 Economy

A definite relationship exists between urban waterways and economy. Examples of the interaction between these two elements include the use of watercourses for aesthetic appeal to elevate property values, the damage caused by floods to properties, and the costs of purification of water for human use.

!	🛠	ⓘ
Discuss economic strengths and weaknesses associated with the urban river	1. Research	
	2. Request information	1. Interest groups

[16] DWAF. 2001. Water Quality Management Series. Managing the Water Quality Effects of Settlements. DWAF, Pretoria.

2.3 Built Environment

The built environment refers to all man-made structures in or alongside urban watercourses.

2.3.1 Dam

Dams are man-made impoundments or reservoirs, whereas lakes are natural waterbodies. Weirs are small overflow type dams, often used to measure flow rates.

In an urban setting, dams are mostly created to provide water supply, control floods, generate hydroelectric power, provide recreation areas and for water abstraction purposes (e.g. for irrigation).

A common phenomenon with urban watercourses is organic (phosphates and nitrates) enrichment of impoundments (i.e. eutrophication). This results in oxygen depletion, dense algal growths, poor odours and discolouration of the water. Some additional problems associated with urban dams include the overabundance of sediment (leading to the rapid filling of the impoundments), disruption of the flow regime, changes in downstream water chemistry, failure of management to satisfy downstream ecological needs, restriction of migrating fish, clear water erosion downstream of dam, resettlement, changes in form and functioning of wetland ecosystems and increase in mosquitoes.

!	🛠	ⓘ
Research	1. Survey	1. Maps – Topographical map
Research	1. Research	1. Past reports
List the problems associated with the urban dam(s)	1. Research	1. Past reports
	2. Request information	1. Interest groups
	3. Specialist study	1. Specialist
Locate gauging weirs (/flow gauging stations)	1. Request information	1. DWAF[17]

[17] DWAF Directorate: Hydrological Services – Tel: (012) 336 7500

2.3.2 Treatment Plants

Wastewater, generated by the mining, industry and domestic water sectors, is purified by treatment plants through physical, chemical and biological processes. Treatment facilities may be regional (i.e. treating wastewater from various dischargers) or on-site (i.e. on premises of discharger). Waste can also be discharged into municipal sewer systems, to be treated by sewage treatment plants. Effluent disposed off into watercourses from an outfall pipe is viewed as pollution point source.

Under the old Water Act of 1956, a uniform standard was used to control effluent discharges. With the new NWA water resource protection is the order of the day and the Receiving Water Quality Objective (RWQO) approach has been adopted.

Local authorities are charges with supplying water and sanitation services, and are also responsible for the management of the subsequent wastewater and sewage treatment.

!		
Locate treatment plants in study area	1. Survey	1. Maps
	2. Research	1. Past reports
	3. Request information	1. DWAF 2. Municipal Engineering Department
Determine problems associated with treatment plants (i.e. authorisation status, compliance with standards)	1. Request information	1. DWAF 2. Municipal Engineering Department

2.3.3 Stormwater Infrastructure

The state of urban rivers is greatly influenced by stormwater. Most urban runoff is collected in stormwater systems, which discharge into the nearest watercourse.

The dominance of impervious areas in cities and towns leads to the rapid conveyance of runoff to the stormwater systems, with resultant flood-related impacts. Stormwater serves as a diffuse pollution source by transporting surface contaminants to the receiving waters.

!	🛠	ⓘ
Through the water quality monitoring programme (SURMP, Section I 2.1.5) and land use description (SURMP, Section I 1.1), identify areas of polluted stormwater ingress.	1. Assessment	1. SURMP, Sections I 1.1 and 2.1.5
	2. Request information	1. DWAF 2. Municipal Engineering Department
	3. Specialist study	1. Specialist

2.3.4 Bridges

Bridges over urban watercourses are mainly used to allow passage of vehicles, trains and people, and for crossings of structures (e.g. pipelines).

Low-lying bridges overflow in cases where a bridge was only designed for smaller flood occurrences or failed to compensate for upstream development in the catchment. Such bridges pose a risk to humans and property.

Bridges in urban watercourses need to be built to cope with strong flows experienced during flash floods and to withstand debris crashing into the structure.

!	🛠	ⓘ
- Identify bridges prone to overflowing - Identify damaged bridge structures	1. Request information	1. Municipal Engineering Department
	2. Specialist study	1. Specialist

2.3.5 Pipelines

As with bridges, pipelines crossing urban water need to be protected to deal with the pressures imposed by floods, floating debris and poor water quality (e.g. acidic water).

Old or damaged pipelines may act as diffuse or point sources of pollution. This is especially the case with sewage pipelines that function as gravity fed systems and are aligned along the natural drainage of the land. These pipelines often run along urban watercourses, allowing any discharges to easily contaminate the nearby water environment.

Where pipelines are construction alongside or across an urban watercourse, erosion protection is needed to reinforce the disturbed riverbank and protect the pipeline.

!		
- Identify areas where flood risks are posed to pipelines. - Identify discharging pipelines.	1. Request information	1. Municipal Engineering Department
	2. Specialist study	1. Specialist

2.4 Management Arrangements

Existing management arrangements for the urban river must be considered. Such arrangements include the *legal framework*, *institutional structures*, *existing management initiatives* and *NWRS* and *RDM requirements*.

2.4.1 Legal Framework

Water is regulated by various policies and laws, of which the National Water Act (No. 36 of 1998) and the Water Services Act (WSA) (No. 108 of 1997) present two fundamental acts overseeing both the management of our nation's water resources and the provision of water services, respectively. As a renewable natural resource, environmental legislation also applies to water resources, in particular the National Environmental Management Act (No. 107 of 1998) and the Environment Conservation Act (No. 73 of 1989).

!	🛠	ⓘ
Provide the legal framework for the SURMP.	1. Research	1. Legislation
	2. Request information	1. DWAF

2.4.2 National Water Resource Strategy Requirements

The NWA stipulates *inter alia* the requirements for the establishment of the National Water Resource Strategy (NWRS), which in turn provides the management framework for our nation's water resources.

At a regional or catchment scale, 19 Water Management Areas (WMA) have been created. The water resources within each of these units are managed by Catchment Management Agencies (CMA). Each CMA must develop a Catchment Management Strategy (CMS) that is in harmony with the NWRS. As forerunners to the CMSs, Internal Strategic Perspectives (ISP) have been prepared by DWAF for each WMA.

!	🛠	ⓘ
Ensure correlation between SURMP and CMS (if available) or ISP.	1. Research	1. CMS/ISP[18]
	2. Request information	1. DWAF

[18] DWAF Directorate: Water Resources Planning – Tel: (012) 336 7500

2.4.3 Resource Directed Measures Requirements

Resources Directed Measures (RDM) encompass the NWA's approach to water resource management in an ecologically sustainable manner, and sets out the course of action for the determination of the class, Reserve and Resource Quality Objectives (RQO) for the water resources.

!	🛠	ⓘ
Ensure the SURMP meets the requirements of the Reserve, Management Class, Ecological Categories and RQOs (if available)	1. Request information	1. DWAF[19]

[19] DWAF Directorate: Resource Directed Measures – Tel: (012) 336 7500

2.4.4 Institutional Structures

2.4.4.1 Institutional Structures – Formal

Establishing the roles and responsibilities for the management of the urban river promotes co-operative governance between the parties involved, and allows for clarification of the matters of jurisdiction.

Apart from DWAF, who is the custodian of our countries water resources at a national level, the following parties are endowed with governance responsibilities over freshwater:

- Catchment Management Agencies (CMAs);
- Water User Associations;
- Catchment Management Committees;
- Water Service Authorities;
- Water Boards;
- Water Service Committees;
- Advisory Committees; and
- The Water Tribunal.

!	🛠	ⓘ
Discuss the institutional arrangements in the study area.	1. Research	
	2. Request information	1. DWAF

2.4.4.2 Institutional Structures – Informal

In addition to the authorities (charged with formal responsibilities) listed in Section I 2.4.4.1 of the SURMP, other management bodies may exist that partake in the regulation of an urban river on a more informal level. This may include forums, Non-Governmental Organisations (NGO), community groups, etc. It is vital that these groups are acknowledged and involved in the management structure.

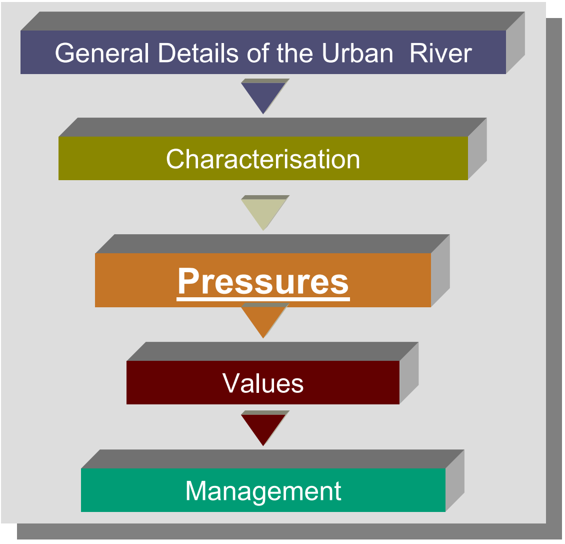
!	🛠	ⓘ
List the informal groups that have an interest in the study area	1. Research	
	2. Request information	1. DWAF 2. Interest groups

2.4.5 Existing Management Initiatives

Existing management tools and structures may already be in place for the management of a specific urban river. If this is the case the guideline user should scrutinise the existing instruments to determine how they could fit into the SURMP.

!	🛠	ⓘ
Identify and examine existing management tools.	1. Request information	1. Formal and informal management institutions (SURMP, Sections I 2.4.4.1 and 2.4.4.2) 2. Interest groups 3. Catchment Forums 4. Municipal Departments (Environmental, Engineering, Parks, etc.)
Incorporate tools/aspects of tools into SURMP (if acceptable)		

3. INVENTORY OF PRESSURES



Knowing and understanding the problems within the urban catchment provides direction to the subsequent management programme, and allows for the preparation of accurate and relevant interventions.

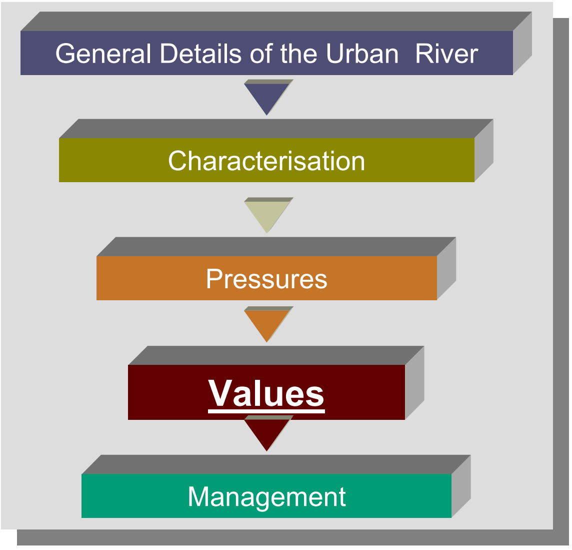
It is vital that the sources of the problems are identified. Too often the symptoms rather that the origins of the impacts are tackled in urban river management. Another key consideration to understanding pressures to urban rivers is causality (i.e. relationship between cause and effect). Evidence of causality may include observations (e.g. euthrophication of dam from organic pollution) or experimental data (laboratory test of polluted water).

Pressures need to be examined in a holistic fashion, where impacts may be interrelated or cumulative.

The characterisation of the urban river (SURMP, Section I 2) serves as the information base for this section.

!		
List and discuss the pressures associated with the urban river in terms of impact sources, adverse effects and causality.	1. Research	1. SURMP, Section I 2

4. INVENTORY OF VALUES



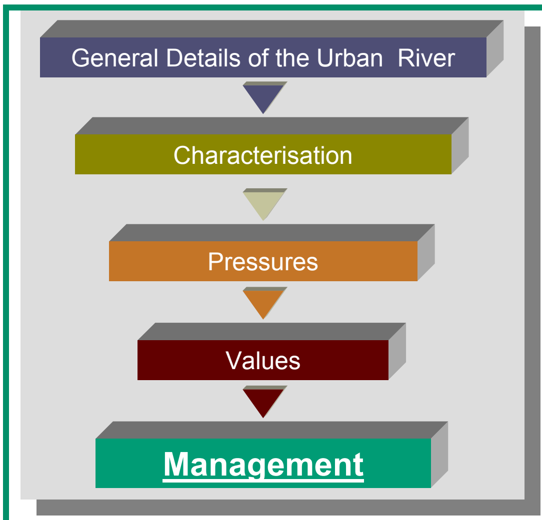
The value of the urban waterway is derived from its goods and services, and reveals what needs to be protected or improved.

The watercourse's values are derived from it natural and socio-economic attributes, as contained in Section I 2 of the SURMP.

The strengths of an urban river are influenced by determining factors, for example indigenous riparian vegetation may be a determinant of aesthetic appeal in a conservation area. In addition, the goods and services of the urban freshwater system may also be subject to threats, which could reduce or remove positive attributes.

!	🛠	ⓘ
List the values of the study area, their determinants and threats.	1. Research	1. SURMP, Section I 2

5. MANAGEMENT PLAN



Section I 2 of the SURMP provides the necessary groundwork for the management plan by examining the natural and socio-economic attributes and the built environment, and by establishing the existing management arrangements for the urban river. The next step is developing the management component of the SURMP, which encompasses the *urban river vision*, *management actions* and *monitoring and auditing*.

5.1 Urban River Vision

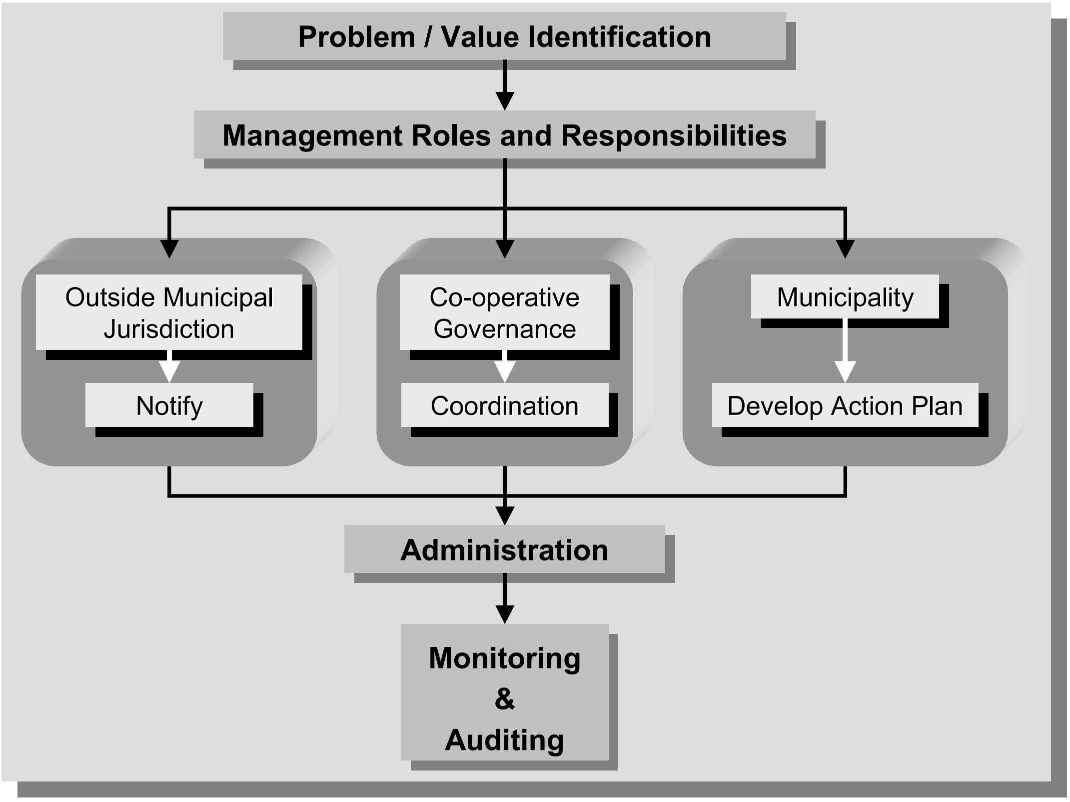
A vision presents a high-level statement regarding future aspirations for the urban river. The vision grants direction to management endeavours, where all activities associated with the regulation of the urban river must occur under the guidance of the vision.

A vision should include the principle of equity and should allow all stakeholders to play a role in the setting of the vision. The end goal is creating a concise statement regarding the desired future of the urban river, with agreement and support from stakeholders.

!		
Generate a vision for the urban river.	1. Research	1. SURMP, Section I 2.2.1
	2. Public participation	1. Formal management institutions (SURMP, Section I 2.4.4.1) 2. Informal management institutions (SURMP, Section I 2.4.4.2) 3. Interest groups

5.2 Management Process

The following diagram broadly illustrates the management process, as discussed in the sections of the SURMP to follow.



5.2.1 Problems Identification

Problems related to the urban river serve as triggers for management actions. Problems may be identified during the profiling exercise (Sections I 2 and 3 of the SURMP) or on an *ad hoc* basis (e.g. site inspections, monitoring results, civil complaints).

!	🛠	ⓘ
Identify problems	1. Research	1. SURMP, Sections I 2 and 3
Generate criteria and prioritise problems for management actions		

5.2.2 Values Identification

Urban river management should not just be geared towards responding to problems. The goods and services of the urban river, as highlighted in Sections I 2 and 4 of the SURMP, need to be protected or enhanced.

!	🛠	ⓘ
Identify values	1. Research	1. SURMP, Sections I 2 and 4
Generate criteria and prioritise values for management actions		

5.2.3 Management Roles and Responsibilities

5.2.3.1 Co-operative Governance

Under the ambit of co-operative governance, common affairs are dealt with in a co-operative and accommodating manner by the various institutions involved. The level of co-operative governance depends on the impact, responsible party and intervention needed. DWAF and the CMAs are legally mandated to oversee water resource management on a national and WMA level, respectively. Apart from these authorities, urban watercourses should also be managed with the involvement of other relevant formal and informal parties.

!	🛠	ⓘ
Ensure adherence to co-operative governance principle		

5.2.3.2 *Municipal Role*

Every municipality should acknowledge the impacts caused by the urban complex on local watercourses, and should proactively take part in managing the state of the water resources within their catchment. Regional, national and international obligations in terms of the water resources traversing municipal boundaries should also receive the deserved attention when formulating management plans.

For those aspects that fall outside municipal jurisdiction, responsible parties are notified and management efforts are merely recorded for auditing purposes. Where management duties rest solely on the municipality, actions should be thoroughly planned and administered. Pressures or values may also be addresses as a joint venture between the municipality and another party. In this case, cooperation in terms of project planning, implementation, administration and tracking is required.

Urban waters are affected by the activities of various municipal departments, for example engineering, town planning and parks departments. There is thus a municipal need to address urban river management both internally as well as externally (i.e. private and public sectors). It is recommended the development and execution of the SURMP be assigned to the municipal department already tasked with environmental management, as the urban river should be managed within the natural and socio-economic environmental spheres of the municipality.

!		
Assign responsibilities within the municipality for the development of the SURMP and execution of management actions		
Determine areas of jurisdiction		SURMP, Section I 2.4.4

5.2.3.3 Funding

Interventions may be funded either by the responsible authority, outside benefactors or by the party responsible for the pressure (e.g. polluters, regulative contraveners).

It is crucial that the financial responsibilities and constraints be determined prior to selecting interventions, as this may affect the feasibility and type of intervention to be implemented.

Investigations into the financial resources may also occur after a suite of possible interventions has been devised.

!	🛠	ⓘ
Determine funds available.		

5.2.4 Action Plans

Where municipalities are designated as the responsible management party control measures need to be established to address the **pressures** placed on the urban watercourse. In addition, measures are required to maintain, enhance or reinstate the determined **values**. An Action Plan presents a formal means of structuring interventions, and contains the following crucial elements:

- The problem or value to be managed (SURMP, Section I 5.2.1-5.2.2)
- Stakeholders (SURMP, Section I 5.2.3)
- Management Action(s)
- Timeframes for intervention

!	🛠	ⓘ
Develop Action Plan for identified pressures and values		SURMP, Section I 5.3.4.1 -5.3.4.2

5.2.4.1 *Management Actions*

Appendix B lists examples of typical impacts associated with the attributes of the urban river together with alternatives of intervention types and potential stakeholders. **Appendix C** provides an assortment of river restoration and management instruments, together with their benefits and constraints.

!	🛠	ⓘ
Peruse Appendix B and C for possible interventions and relevant stakeholders.		SURMP guidelines, Appendix B and C

5.2.4.2 *Intervention Timeframes*

Resources may not permit all pressures and values to be managed as and when they are identified.

Interventions need to be prioritised in terms of resource allocation and timeframes. Criteria for prioritisation of **pressure**-related interventions may include *inter alia* the severity (i.e. extent and magnitude) of the problem, the affects to other water users, cumulative impacts, priority areas, legislative obligations, cost vs. benefits and manageability of the problem.

Prioritisation of management efforts regarding **values** may include factors such as the necessity, beneficiaries, cost vs. benefits, priority areas and strategic importance.

!	🛠	ⓘ
Generate criteria and prioritise problems and values for management actions		
Assign timeframes for initiation and completion of interventions		

5.3 Monitoring and Auditing

The monitoring and auditing stage of the SURMP relates to tracking and evaluating the implementation effectiveness of the management actions. Performance criteria include the following:

- Elimination or reduction of problem/enhancement, maintenance or reintroduction of value;
- Improvement to the urban river environment;
- Stakeholder satisfaction and support; and
- Alignment of results with the urban river's vision (SURMP, Section I 5.1).

An unsuccessful management action may lead to adjustments in the decision-making process to rectify mistakes and prevent re-occurrence.

!		
Develop performance criteria		
Monitor effectiveness of management actions		

9. GEOGRAPHICAL INFORMATION SYSTEM

A GIS is a computer-based system which assembles, stores, manipulates and displays geographically referenced data. As part of the SURMP it is strongly suggested that a GIS be created and all information that is amenable to spatial representation be added to the system.

The urban river GIS captures information with spatially referenced data such as geographical coordinates, recorded with a handheld Global Positioning System (GPS).

On the GIS, the attributes of the urban river should be accompanied by an information sheet that includes details of the locality, status, threats, determinants, weaknesses, problems, stakeholders, etc. associated with the attribute. Photographs of the features and other points of interest should also be linked to the system.

The GIS should further contain management actions that can be visually presented, together with information on the intervention type, responsible parties, timeframes, etc. Photographs before and after interventions may add additional value to this component.

One of the major benefits associated with any GIS is that it is incrementally built, which permits an increase in both sophistication and the quantity of spatial data that can be depicted. The dynamic nature of the GIS implies that information can to be fed into the system continuously to indicate spatial changes occurring to the urban river.

The functionality of the urban river GIS is as follows:

- It allows for a quick scan and spatial understanding of the urban river;
- It provides an overall view of the management actions which emanate from the SURMP; and
- It complements decision-making by rendering a dynamic and user-friendly management tool.

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APPENDIX A

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Typical Urban River Impacts, Possible Interventions and Stakeholders

ATTRIBUTE	PROBLEM	POSSIBLE INTERVENTION	STAKEHOLDERS
Land Use	Non-compatible with land development plans	RSDF, LIDP, LDO enforcement	Municipal Town Planning Department
	Projects, governed by legislation, executed without requisite approval	Notify Designated Authority	- DWAF - Provincial Department of Environmental Affairs - Municipal Environmental Department
	Development within the 1:100 year floodline		
Water Use	Unauthorised use of water	Notify Designated Authority	- DWAF - Provincial Department of Environmental Affairs
	Non-compliance with authorisation conditions		
Water Quality	Water quality hotspots	Identify and address pollution source	- DWAF - Municipal Environmental Department
	See **Appendix C**		
Flora	Illegal removal of riparian vegetation	Notify Designated Authority	- DWAF - Municipal Parks and Environmental Departments
	Illegal damage to priority plants (i.e. protected species)		- Provincial Department of Environmental Affairs
	See **Appendix C**		

ATTRIBUTE	PROBLEM	POSSIBLE INTERVENTION	STAKEHOLDERS
Fauna	Reduction in aquatic fauna biodiversity (e.g. biomonitoring results)	Determine linkage with physical or chemical water quality variables	- DWAF - Municipal Environmental Department
		Identify and address impact source	
	Illegal damage to priority animals (i.e. protected species)	Notify Designated Authority	- Provincial Department of Environmental Affairs
Wetlands	Alterations to wetland structure or function	Identify and address impact source	- DWAF - Provincial Department of Environmental Affairs - Municipal Environmental Department
	See **Appendix C**		
Estuaries	Alterations to estuary structure or function	Identify and address impact source	- DWAF - Provincial Department of Environmental Affairs - Relevant Coastal Management Institution - Municipal Environmental Department
	* Breen C. M., & McKenzie M. 2001. Managing estuaries in South Africa: An Introduction. Institute of Natural Resources, Pietermaritzburg. * Hay D. & McKenzie M. 2005. Managing Estuaries in South Africa: A Step by Step Guide. Water Research Commission, Pretoria		
Heritage Resources	Damage to heritage resources	Identify and address impact source	- Provincial Heritage Resource Agency

ATTRIBUTE	PROBLEM	POSSIBLE INTERVENTION	STAKEHOLDERS
Public Health	Water unfit for human contact/ingestion	- Identify and address impact source - Notify Designated Authority	- Municipal Health and Environmental Departments
	Informal housing located within the floodplain		
	Hotspots for risk of human drowning		
Dense Settlements	Polluted runoff	Notify Designated Authority	- CMA - DWAF - Municipal Environmental Department
	Disposal of waste into urban river		- Municipal Waste Department
	Inadequate services (including vandalism, maintenance problems, etc.)		- Municipal Engineering and Housing Departments
	Livestock		- Municipal Health Department
	See **Appendix C**		
	* DWAF. 2001. Water Quality Management Series. Managing the Water Quality Effects of Settlements. DWAF, Pretoria.		

ATTRIBUTE	PROBLEM	POSSIBLE INTERVENTION	STAKEHOLDERS
Impoundments	Pollution (e.g. euthrophication)	Identify and address pollution source Notify Designated Authority	- DWAF - Municipal Environmental Department
	Downstream erosion	Attenuation, energy dissipation and stabilisation efforts	- Municipal Engineering and Environmental Departments
	Unsafe dam	Notify Designated Authority	- DWAF - Municipal Engineering Department
	Failure to meet downstream water quantity requirements		- DWAF
	Projects, governed by legislation, executed without requisite approval		- DWAF - Provincial Department of Environmental Affairs - Municipal Environmental Department
	See **Appendix C**		
Treatment Plants	Non-compliance with licence conditions	Notify Designated Authority	- DWAF
	Non-payment of waste discharge charge		
	Projects, governed by legislation, executed without requisite approval		- DWAF - Provincial Department of Environmental Affairs - Municipal Environmental Department

ATTRIBUTE	PROBLEM	POSSIBLE INTERVENTION	STAKEHOLDERS
Stormwater	Diffuse pollution	Identify and address impact source	- DWAF - Municipal Environmental Department
	Projects, governed by legislation, executed without requisite approval	Notify Designated Authority	- DWAF - Provincial Department of Environmental Affairs - Municipal Environmental Department
	Damaged infrastructure	Notify Designated Authority	- Municipal Engineering Department
	Flooding and related problems (e.g. erosion)	Attenuation, energy dissipation and stabilisation efforts	
	See **Appendix C**		
	* Pegram G. & Görgens A. 2000. A Guide to Nonpoint Source Assessment to Support Water Quality Management of Surface Water Resources in South Africa. Water Research Commission, Pretoria.		
Bridges	Damaged infrastructure	Notify Designated Authority	- Municipal Engineering Department
	Unsafe bridge		
	Projects, governed by legislation, executed without requisite approval		- DWAF - Provincial Department of Environmental Affairs - Municipal Environmental Department

ATTRIBUTE	PROBLEM	POSSIBLE INTERVENTION	STAKEHOLDERS
Pipelines	Discharging Unsafe pipeline Damaged infrastructure	Notify Designated Authority	- Municipal Engineering Department - Pipeline custodian
	Projects, governed by legislation, executed without requisite approval	Notify Designated Authority	- DWAF - Provincial Department of Environmental Affairs - Municipal Environmental Department

APPENDIX C

General Stormwater Management and River Restoration Techniques

INTERVENTION MEASURE	CONCISE DESCRIPTION	BENEFITS	CONSTRAINTS
Detention Ponds	Detention systems capture a volume of runoff and temporarily retain that volume for subsequent release. Detention systems do not retain a significant permanent pool of water between runoff events.	Flood attenuation; pollution control.	Sufficient precipitation required to maintain pool; requires large area; maintenance necessary; aesthetically unpleasing; mosquito breeding; odours.
Retention Ponds	Retention systems maintain a significant permanent pool volume of water between runoff events. The main pollutant removal mechanism in retention systems is sedimentation.	Pollution control.	Requires a large area; thermal pollution; odours; algal blooms; regular maintenance; mosquito breeding.
Stabilisation ponds	Ponds designed to treat raw, settled domestic waste, septic tank effluent, night soil, or conservancy tank contents (Campbell et al., 2001)	Reduce nutrient and bacteriological levels.	Odour problems under anaerobic conditions; large area required.
Rock Filters	Runoff flowing over rock filter percolates through medium and undergoes bio-chemical reactions.	Captures debris; removes nutrients.	Regular maintenance.
Sand Filters	Runoff flowing over sand filter percolates through medium and undergoes bio-chemical reactions.	Captures debris; removes nutrients.	Regular maintenance.

INTERVENTION MEASURE	CONCISE DESCRIPTION	BENEFITS	CONSTRAINTS
Infiltration basin	An infiltration basin is a shallow impoundment which is designed to infiltrate stormwater into the ground water.	Cost-effective; recharges ground water; improvement of water quality.	Potentially aesthetically unpleasing, possible mosquito breeding. Concerns over ground water contamination and sufficient soil infiltration, high maintenance; relatively high failure rate.
Infiltration Trenches	A rock-filled trench with no outlet that receives stormwater runoff. As the latter passes through the trench, stormwater runoff passes through some combination of pre-treatment measures, such as a swale and detention basin, and into the trench. There, runoff is stored in the voids of the stones, and infiltrates through the bottom and into the soil matrix. The primary pollutant removal mechanism of this practice is filtering through the soil	Filtering of runoff to improve water quality.	Concerns over ground water contamination and other soils requirements; high maintenance; relatively high failure rate.
Grass swales	Broad, shallow channel with a dense stand of vegetation covering the side slopes and bottom.	Filters runoff to improve water quality. Partial stormwater attenuation.	Cannot treat a very large drainage areas; mosquito breeding; thick vegetative cover needed to function properly.
Grass Plots	Plots of open grassland with 1:60 to 1:120 slope (Campbell et al., 2001)	Pollution control.	Large area required.

INTERVENTION MEASURE	CONCISE DESCRIPTION	BENEFITS	CONSTRAINTS
Buffer Strips	Placement of grass buffer strips in riparian areas.	Runoff purification; stormwater retention.	Maintenance.
Disinfection	Dosing of water column with disinfectants.	Removal of pathogens.	Requires specialist input; expensive; may be environmentally unfriendly.
Phosphate Chemical Precipitation	Precipitation of nutrients from water column.	Removal of phosphorus and nitrogen.	Large quantity of sludge produced which needs to be removed; relatively expensive in the case of alum utilisation.
Bioremediation	Addition of microbial populations to speed up the process of denitrification.	Reduction of nitrate levels; natural; reduces odour; This technique leads to substantial cost savings.	Environment must be carefully controlled and monitored for optimal microbial growth; some engineering of the site may be necessary.
Artificial Wetlands	Construction of a wetland system to obstruct and filter overland flow.	Runoff attenuation and cleansing; provides faunal habitats; low maintenance; run by relatively untrained personnel.	Must be situated in low lying areas with high water table; adequate design necessary; mosquito breeding.

INTERVENTION MEASURE	CONCISE DESCRIPTION	BENEFITS	CONSTRAINTS
Vegetated Filter Strips	Removal of sediment and other pollutants from runoff and wastewater by filtration, deposition, infiltration, absorption, adsorption, decomposition, and volatilisation	Vegetated filter strips can improve water quality by removing nutrients, sediment, suspended solids	Appropriate for predominantly sheet flow runoff; soils should be reasonably well drained; bedrock and the water table should be below the surface; slopes should be less than 15 %; not appropriate for hilly or highly paved areas because of high velocity runoff.
Bioaugmentation	Application of selected micro organisms to enhance the microbial populations of an operating waste treatment facility.	Improves water quality; reduces operating costs.	Environment must be carefully controlled and monitored for optimal microbial growth and some engineering of the site may be necessary.
Revegetation	Techniques such as direct seeding, planting, transplanting, pre-seeded matting and brush used to re-establish riparian vegetation.	Erosion control, water purification, recreational endorsement	Requires maintenance, e.g. weed control.

INTERVENTION MEASURE	CONCISE DESCRIPTION	BENEFITS	CONSTRAINTS
Artificial Riffles	Construction of riffles at applicable sites utilizing suitable rocks.	Prevention of channel deepening; erosion protection; flow attenuation; creation of biota habitat, aeration of water column; aesthetically pleasing.	Rocks may be dislodged and transported downstream during floods.
Rock and grass chutes	A section of the riverbed is hardened with graded rock.	Increases bed resistance; reduces the slope of a river;	Impedes passage of aquatic fauna; technique most applicable on seasonal waterways or where base flows are low.
Grass chutes	A section of the channel is vegetated with dense grass.	Reduces the velocity of flows, trapping sediment and inhibiting erosion. Low cost.	Inappropriate in channels exposed to heavy livestock grazing/prolonged inundation. Ongoing maintenance. Difficulties establishing grass.
Sediment management	Excavating sediment deposited on the inside of bends.	Re-establishment of riverbed.	Might require earthworks within channel.
Installing large woody debris.	Large woody debris installed to stabilise channel alignment by directing flows away from the toe of the riverbank. Stream flow smoothly directed around the meander and to the centre of the channel. Logs typically installed against outer bank, pointing downstream at an angle.	Cheaper than removal of logs.	Debris might be dislodged during floods to pose risk to humans and promote bank erosion.

INTERVENTION MEASURE	CONCISE DESCRIPTION	BENEFITS	CONSTRAINTS
Flow Retards and Groynes	Retards and groynes are flow obstructions protruding from the bank, angled downstream into the channel of the waterway.	Stabilise channel alignment and meanders; erosion protection; control channel width and form	Structures may fail in fast flowing waterways.
Vane Dykes	series of short vane structures positioned mid-stream along an eroding bank to encourage sediment deposition.	Reduce bank erosion on outer bends and control channel alignment.	Technique not as effective in straight or irregularly aligned rivers.
Battering and terracing	Earthworks used to reshape the bank to an even slope.	Facilitates re-establishment of vegetation.	Requires earthworks; initially erosion could be exacerbated..
Brushing	Cut trees or branches used to provide superficial bank protection.	Controlling bank erosion; low cost; environmental benefits (creating instream habitat and food sources.	Not as stable as harder methods and may not be effective where deep and powerful flows are experienced.
Organic geotextiles	Vegetative mats used to stabilise banks and prevent soil loss caused by overland flow and a lack of vegetative cover.	Stabilise banks; enables germination; suppresses weed growth; biodegradable; reduces changes in soil temperature; decrease evaporation; and improve infiltration and soil water moisture content.	Requires both heavy equipment and intensive manual labour to install.

INTERVENTION MEASURE	CONCISE DESCRIPTION	BENEFITS	CONSTRAINTS
Log Walling	Log wall constructed along base of eroding bank to hold bank material in place.	Provides toe protection from undercutting, treatment of bank slumping; sturdy.	Cannot be built on hard riverbeds; availability of materials, space, cost and access to the site for heavy machinery; unaesthetic, prevents access to river; destruction of natural habitats.
Rock Gabions	Large, rectangular mesh wire cages filled with stone used to build a retaining wall along the base of an eroding bank.	Holds bank material in place and prevents slumping; flexible; permeable, little construction expertise and maintenance; sturdy; roughness.	Aesthetically unpleasing; prevents access to river; destruction of natural habitats.
Rock Riprap	Consists of a layer of rock placed on a riverbank. Bank is rock paved usually to above high water mark.	Applicable to most types of bank erosion; provides long-term protection; sturdy.	Aesthetically unpleasing; prevents access to river; destruction of natural habitats.
Boulders	Boulders placed instream to perform various functions.	Bank stabilisation; roughness; lends visual quality, provides fish habitat.	Boulders may be dislodged and transported downstream during big floods; may divert scouring to another section of the riverbank.

INTERVENTION MEASURE	CONCISE DESCRIPTION	BENEFITS	CONSTRAINTS
Rock mattresses	Empty wire mesh mattresses laid into position, wired together and filled with rock.	Improves strength of soil structure; flexible; long life; sturdy; facilitates revegetation; allows free drainage and greater opportunity for biological activity.	The bank may require battering, to an even slope prior to placing the mattresses; mattresses may need to be temporarily pegged into position during installation on steep banks; suitable local sources of fill material should be investigated when assessing the feasibility of the technique.
Porous Pavement	Permeable pavement which allows runoff to infiltrate hard surface (e.g. parking area).	Reduces runoff; partial water quality treatment.	Strict siting requirements; high failure rate.
Water Quality Inlets	Consists of a series of chambers, namely a sedimentation chamber, an oil separation chamber and a discharge chamber. Pretreatment of runoff.	Traps litter, debris, oil and grease, and other floatables; often used where land requirements and cost prohibit the use of larger BMP devices, such as ponds or wetlands; used to treat runoff prior to discharge to other BMPs.	Effective for small drainage area; relatively high maintenance; does not provide adequate stormwater quantity control due to the limited storage.

INTERVENTION MEASURE	CONCISE DESCRIPTION	BENEFITS	CONSTRAINTS
Bioretention	Surface runoff is directed into shallow, landscaped depressions. During storms, runoff ponds above the mulch and soil in the system, and filters through the mulch and prepared soil mix. Typically, the filtered runoff is collected in a perforated underdrain and returned to the storm drain system.	Ground water recharge; pollutant removal; ideally suited for densely developed area.	Intended for small sites; regular maintenance required; relatively high construction costs.
Catch basin	An inlet to the storm drain system that typically includes a grate or pavement inlet and a sump.	Captures sediment, debris, and associated pollutants.	Unless frequently maintained, catch basins can become a source of pollutants through resuspension.
Stormwater Retrofitting	A stormwater retrofit is a stormwater management practice (usually structural) put into place after development has occurred.	Improves water quality; protects downstream channels; reduces flooding; meet a variety of river restoration objectives	
In-Line Storage	Practices designed to use the storage within the storm drain system to detain flows. Storage is achieved by placing devices in the storm drain system to restrict the rate of flow.	Controls flow; low maintenance.	If improperly designed, these practices may cause upstream flooding; dependable on storage available in the storm drain system

INTERVENTION MEASURE	CONCISE DESCRIPTION	BENEFITS	CONSTRAINTS
Deflector	Deflectors are blunt, wedge-shaped rock structures that are embedded in the bed and bank and project into the flow.	Bank protection; facilitates plant establishment.	Partially destroys natural habitat and is aesthetically unpleasing.
Live Cribwall	A live cribwall is a rectangular framework of logs or untreated timbers, rock, and woody cut-tings.	Repairs eroding banks; useful when space is limited and slopes cannot be cut back; provides excellent overhang cover material for aquatic habitat.	Requires fill material.
Sloping	Creating a gradient along steep, eroded banks.	Facilitates plant establishment; aesthetically pleasing; enables access to river.	Requires toe protection; should be built during low flow conditions as they often require work in the channel bed; requires a moderate amount of live material. Regular inspection is necessary in the first year.
Loffelstein	Concrete revetments.	Bank stabilisation.	Expensive; environmentally and aesthetically unpleasing.
Upgrading	Upgrading implies the renovation of existing structures.	Improvements to target specific requirements; use of existing structures.	Investigation of structure integrity.

INTERVENTION MEASURE	CONCISE DESCRIPTION	BENEFITS	CONSTRAINTS
Concrete dissipators	Grouting concrete cubes into conveyance system.	Decrease in flow velocity.	Must withstand forces of strong flow.
Rebuilding Meanders	Increasing the sinuosity (i.e. a measure of the amount of a river's meandering) of a river.	Restores channel stability on straight drains; creates a more aesthetic landscape, with higher environmental value.	Requires space; additional stabilisation works will be required to control the bed and banks following construction; costly; time consuming.
Weir	Device for measuring or regulating the flow of water.	Reduces peak flow.	Impedes passage of aquatic fauna.