GCRO RESEARCH REPORT
# NO. 11

# TOWARDS APPLYING A GREEN INFRASTRUCTURE APPROACH

## IN THE GAUTENG CITY-REGION


**DECEMBER 2019**
**Edited by**
Christina Culwick and Samkelisiwe Khanyile
**Contributions by**
Kerry Bobbins, Christina Culwick, Stuart Dunsmore, Anne Fitchett, Samkelisiwe Khanyile, Lerato Monama, Raishan Naidu, Gillian Sykes, Jennifer van den Bussche and Marco Vieira



GCRO | Gauteng City-Region Observatory

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**December 2019**

Photograph by Alastair Mclachlan

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Photograph by Mpumelelo Buthelezi

## Glossary of key terms

**ECOSYSTEMS**
Biological communities and their non-biological (physical) environment that together sustain life.

**ECOSYSTEM SERVICES**
The benefits provided by ecosystems (ecological systems or ecological assets) to society.

**GREEN ASSET**
All natural and planted ecological features of a landscape. This can include trees, wetlands, parks, green open spaces, vegetated features deliberately designed into the built-environment (such as green walls and roofs on buildings, or road and pavement adaptations such as permeable paving, swales, bio-retention areas and buffer strips), as well as original grassland and woodlands, etc.

**GREEN ASSET REGISTRY**
Non-monetary information regarding the extent and condition of ecosystems, and expected ecosystem service flows.

**GREEN INFRASTRUCTURE**
The interconnected set of natural and constructed ecological systems, green spaces and other landscape features that together form a network providing services and strategic functions in the same way as traditional 'hard' infrastructure.

**(TRADITIONAL) GREY ASSETS**
Man-made or engineered systems and other features that involve the use of traditional technology and building materials such as concrete, bricks and impermeable surfaces.

**GREY-GREEN INFRASTRUCTURE**
Combined grey-green infrastructure solutions that incorporate both ecological and traditional infrastructure features.

# Acronyms and abbreviations

| | |
|---|---|
| CBA | cost–benefit analysis |
| CBD | central business district |
| COD | chemical oxygen demand |
| CoGTA | Department of Cooperative Governance and Traditional Affairs |
| CoJ | City of Johannesburg |
| CSIR | Council for Scientific and Industrial Research |
| DBSA | Developmental Bank of South Africa |
| DWAF | Department of Water Affairs and Forestry |
| DWS | Department of Water and Sanitation |
| EA | enumeration area |
| EAU | ecosystem accounting unit |
| EIA | environmental impact assessment |
| GCR | Gauteng City-Region |
| GCRO | Gauteng City-Region Observatory |
| GDARD | Gauteng Department of Agriculture and Rural Development |
| GI | green infrastructure |
| GIS | geographical information systems |
| GRAP | Generally Recognised Accounting Practice |
| GTI | GeoTerra Image |
| IDP | Integrated Development Plan |
| JDA | Johannesburg Development Agency |
| LCEU | land cover/ecosystem functional unit |
| MFMA | Municipal Finance Management Act, No. 56 of 2003 |
| NDVI | normalised difference vegetation index |
| SAL | small area layer |
| SANBI | South African National Biodiversity Institute |
| SAWQG | South African Water Quality Guidelines |
| SDF | Spatial Development Framework |
| SEEA | System of Environmental-Economic Accounting |
| SIP | Strategic Integrated Project |
| SPLUMA | Spatial Planning and Land Use Management Act, No. 16 of 2013 |
| StatsSA | Statistics South Africa |
| SUDS | sustainable urban drainage systems |
| WASSUP | Water, Amenities, Sanitation Services, Upgrading Programme |
| WERF | Water Environment Research Foundation |
| WRC | Water Research Commission |

# Acknowledgements

## General
This report is the product of research undertaken between 2015 and 2018 and has relied on the guidance, support and input from a number of people. We would like to acknowledge everyone who has contributed to this report from concept to finalisation. Kerry Bobbins played a critical part in conceptualising the case studies presented in this report, including shaping and editing one of them. Kerry also provided a constructive review on the overall report. We would also like to acknowledge the GCRO research committee, Carla Washbourne and the blind peer-reviewer, who provided valuable comments and suggestions. Graeme Götz has played an important role, initially in helping to shape the case studies and then in reviewing the report. Finally, we would like to acknowledge the CityLab participants who participated in directing and shaping the case studies based on what is needed to further the application of a green infrastructure approach in Gauteng.

## Chapter acknowledgements
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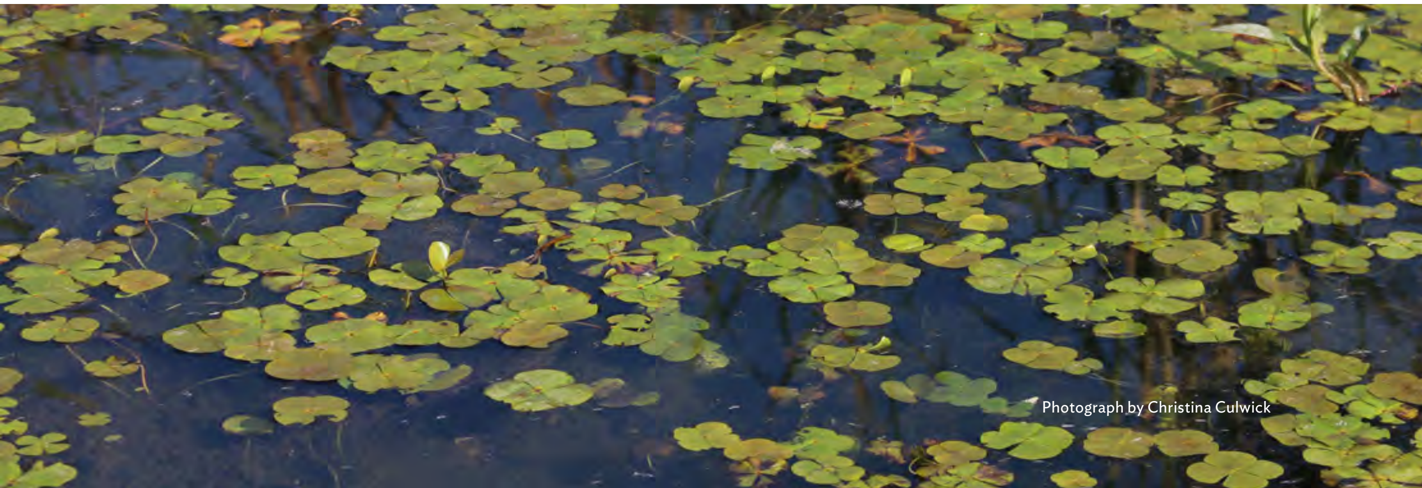
**Chapters 3 and 4** were prepared in collaboration with a number of people. The core team of researchers included Anne Fitchett of the School of Civil and Environmental Engineering, University of the Witwatersrand, Lerato Monama of WASSUP Diepsloot and Jennifer van den Bussche of Sticky Situations. The core researchers would like to acknowledge the collaboration and knowledge exchange of the various residents in the two study sites described in this report. Thanks also go to members of Bontle Ke Tlhago for their contribution in labour and for assisting in arranging the removal of waste at Site 2 by Pikitup, and members of WASSUP Diepsloot who repaired communal toilets and taps at the research work site. Acknowledgement is also due to Maria Heyneke, Megan van der Haar and Givarn Singh, who provided visual material to support the initial community engagement, assisted with the initial sketches used in this chapter, performed the water testing and analysis, and assisted in the final writing of the report.

The author of **Chapter 6**, Gillian Sykes, acknowledges that writing her chapter would not have been possible without innumerable conversations with her colleagues, with special thanks to Ian Palmer, Nick Graham and Kim Walsh.



Photograph by Christina Culwick

## About the authors

### **Chapter 1:** Christina Culwick (ORCID: 0000-0003-2710-9797)

**Christina Culwick** is a senior researcher at the Gauteng City-Region Observatory (GCRO), with research interests in urban sustainability, infrastructure transitions, environmental governance, transport and social justice. Her research extends across multiple disciplines, with a specific focus on collaborative knowledge creation and the role of transdisciplinary research for informing policy and governance practices. She has presented and published her research both locally and internationally. Christina completed both undergraduate (BSc Geography & Maths) and postgraduate studies (BSc Hons & MSc Geography) at the University of the Witwatersrand, and is currently a PhD candidate at the University of Cape Town. Beyond her academic research, Christina holds a postgraduate diploma in teaching (UNISA) and previously worked as an SABC broadcasting meteorologist.

### **Chapter 2:** Samkelisiwe Khanyile (ORCID: 0000-0002-7620-7628)

**Samkelisiwe Khanyile** is a junior researcher at the Gauteng City-Region Observatory (GCRO). She holds an MSc in GIS and Remote Sensing from the University of the Witwatersrand, and is currently enrolled for a PhD at the University of the Witwatersrand. She is a member of Women in Mining South Africa (WiMSA) and the Wits Digital Mine Project group. Samkelisiwe's research interests include investigating the impact of mining legacies on natural and human communities, access to mining-related geospatial and attribute information, geospatial data quality and the applications of geographical information systems (GIS) for informing urban development and sustainability-related issues. Samkelisiwe also has a keen interest in story-telling through mapping, spatial analysis, geovisual analytics and other data visualisation techniques.

### **Chapters 3 and 4:** Anne Fitchett (ORCID: 0000-0003-4676-296X), Lerato Monama and Jennifer van den Bussche

**Professor Anne Fitchett** has a BA in Architecture, an MSc in Building Construction, and a PhD in Civil Engineering which explored labour-intensive construction. She lectures in the fields of project management, labour-intensive construction, engineering design and environmental engineering in the School of Civil and

Photograph by Catherine Cawood

Environmental Engineering at the University of the Witwatersrand. Her research interests are in employment creation, innovative structural systems using compacted earth masonry, lean engineering and sustainable urban drainage systems. She has published her work on sustainable drainage systems in Diepsloot, and is a co-author of the City of Johannesburg's Stormwater Manual, which provides guidance for the implementation of the City's stormwater by-laws promoting the use of green infrastructure. She has been published in peer-reviewed journals in all areas of her current research interests.

**Lerato Monama** is a founding member and director of WASSUP, an organisation dedicated to improving water and sanitation conditions in Diepsloot, with a keen interest in environmental challenges. Lerato is treasurer of the organisation, she plays a key role in accountability and leads much of the community participation aspects. Lerato initially studied computers and call-centre training but was attracted to the hands-on entrepreneurial opportunities presented by WASSUP and became a founding member of the WASSUP co-operative. Having learnt her plumbing skills on the job, she obtained her formal basic plumbing qualification in 2018 and is keen to pursue more advanced training. Lerato played a key role in terms of on-the-ground negotiations with local residents, discussing environmentally based solutions and leading the pilot implementation.

**Jennifer van den Bussche** is founder and director of Sticky Situations. A project manager with over 25 years' experience in construction, implementation, community development and research, Jen has a solid background in project implementation and management using collaborative and participatory methodologies to achieve project aims. She studied Architecture and has an MA in International and Community Development from Deakin University (Australia), and is a research affiliate of the Earth Institute at Columbia University's Centre for Sustainable Urban Design, New York. Jen believes in the power of community to create sustainable change, and that only by working together can we achieve positive outcomes for the spaces and places we work in.

**Chapter 5:** Stuart Dunsmore, Raishan Naidu and Marco Vieira

**Stuart Dunsmore** is a registered professional engineer (RSA & UK), a chartered water and environmental manager (CIWEM, UK), and a water resource specialist. He holds a BSc in Engineering (Agriculture) and an MSc in Engineering (Hydrology), both from the University of Natal. He has over 30 years' experience in the water sector, mainly in river engineering, flood management, catchment analysis and stormwater management, and he specialises in sustainable engineering solutions. Over the last decade, Stuart has been particularly active in urban surface water solutions and has collaborated with local and provincial government in Gauteng in the application and implementation of sustainable drainage practices, nature-based solutions and urban catchment recovery. He is co-author of the recent City of Johannesburg Stormwater Design Manual (2019) and has designed the first regional constructed wetland treatment system for the City of Ekurhuleni. Stuart is a Director of Fourth Element Consulting and part of the Urban Rivers Alliance with Aqualinks and Eco-Pulse.

**Raishan Naidu** holds a BSc in Engineering (Agriculture) from the University of KwaZulu-Natal. He is a registered professional engineer (ECSA) with more than ten years' experience in the water engineering sector as a water resource engineer. He is a specialist in surface water engineering, with expertise in hydrological and hydraulic modelling, design, flood analysis and stormwater management for the urban, mining, industrial and agricultural sectors. During his employment at Fourth Element Consulting, between 2011 and 2015, Raishan became the Manager of the Engineering and Hydrology Department, working on several complex flood management and river engineering projects, incorporating innovative engineering solutions with ecologically sensitive designs. Raishan is currently the Regional Manager for the Infrastructure Business Unit (Gauteng and Northern Regions) at Nako Iliso, leading and managing a civil engineering team in a wide range of municipal infrastructure projects.

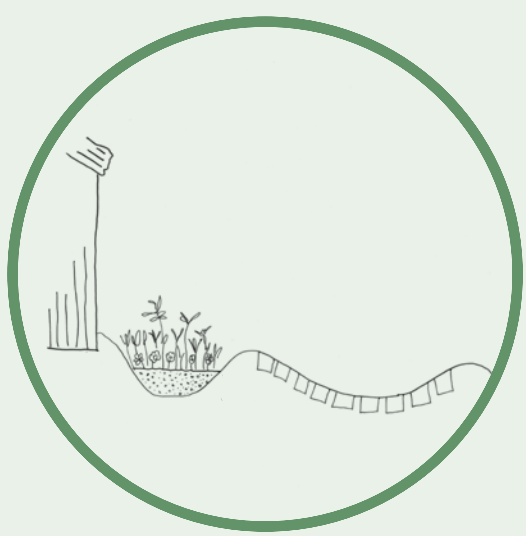
Photograph by Andiswa Nkosi

**Marco Vieira** holds a BSc in Ecology, Zoology and Botany, a BSc (Hons) in Ecology and an MSc in Ecology, all from the University of the Witwatersrand. He is an Environmental, Social and Governance Consultant, specialising in investment on the African continent in a diverse range of sectors, with a particular focus on agricultural investments. This work has led to a robust knowledge of the interplay between the management of aquatic ecological systems and water budgeting for medium- to large-scale agricultural operations in more than 20 African countries. Other work for a range of investors ranging from pension funds to private equity houses has covered forestry, fertilisers, food and beverage production and waste management in Southern, East and West Africa. His work at Fourth Element Consulting primarily covered the GIS mapping of surface water flow models and the compilation of water-use licence application documentation, as well as adding ecologically focused design elements to in-house engineering solutions.

### **Chapter 6:** Gillian Sykes

**Gillian Sykes** is a former Director of PDG, a multi-disciplinary consulting firm providing research, policy evaluation, strategy planning and management support to the public sector with the ultimate goal of improving people's quality of life. She has undergraduate degrees in Economics, Environmental & Geographical Science, and postgraduate degrees in City and Regional Planning, and Public Policy from the University of Cape Town and the Simon Fraser University (Canada) respectively. Through her 14-year consulting experience, Gillian has had the opportunity to straddle the environmental, fiscal and public infrastructure arenas, and believes that many answers lie in the gaps between different disciplines.

rain garden /
bio-retention



# Chapter 1
# Introduction and overview

*CHRISTINA CULWICK*

## Key points

- Despite the potential of applying a green infrastructure (GI) approach in cities, traditional approaches to urban planning and infrastructure development continue to dominate, in part because of the lack of systematic evidence in GI to support decision-making and project implementation.
- This report, as the third in the series, builds on the foundations laid in the first two reports and phases of the Gauteng City-Region Observatory (GCRO) Green Assets and Infrastructure project. This project has progressed from establishing the theoretical potential of applying green infrastructure in the Gauteng City-Region (GCR) to exploring ways in which the theoretical GI approach could be applied in this context. This report demonstrates how a number of GI projects have been implemented, and provides practical guidance for applying a GI approach more systematically throughout Gauteng.
- This report presents the application of a GI approach in technical detail to further establish the case, and specifically speaks to practical aspects that might be of particular interest to project managers and government officials.
- This report covers four separate focus areas:
  - How innovations in geospatial methods and new spatial datasets have been able to enhance the understanding of Gauteng's green assets and contribute to the argument for adopting a GI approach;
  - How GI can be implemented in an informal settlement context and help tangibly improve the living conditions of people residing in these areas;
  - How GI can provide the equivalent services as traditional infrastructure at a similar capital cost while also providing a range of additional benefits; and
  - Practical guidance on how green assets could be incorporated into municipal accounting systems to further support the investment in, and maintenance of, GI in Gauteng.

## Introduction

Ideas on how to incorporate ecological systems into urban planning and infrastructure projects have gained traction both internationally and in South Africa amidst growing concerns about environmental sustainability, the climate crisis and rapid urbanisation. The green infrastructure (GI) approach[1] has been incorporated into recent international commitments and visions, such as the Paris Agreement on climate change (United Nations Framework Convention on Climate Change [UNFCCC], 2015), the 2030 Agenda for Sustainable Development (United Nations [UN], 2015) and the New Urban Agenda (UN-Habitat, 2016). These high-level commitments acknowledge the value

1 A green infrastructure approach has emerged as an alternative approach (or partner) to traditional infrastructure provision that harnesses the functioning of, and services provided by, ecosystems (Culwick et al., 2016).

of ecological systems within urban development agendas. In doing so, they have added impetus to existing work on enhancing the role of ecological systems and have inspired new programmes, such as the ICLEI–Local Governments for Sustainability's CitiesWithNature initiative.[2]

Attempts to incorporate nature into urban planning date back to some of the earliest urban planning movements (e.g. Ebenezer Howard's 1890s Garden City movement). However, renewed interest in GI has emerged from growing evidence showing that ecological systems can play a valuable role in the urban infrastructure network through materially improving residents' quality of life and access to services. A GI approach, it is argued, would help mitigate some of the negative consequences of urban development, such as urban heat island effects, noise, air pollution and increased stormwater that can lead to flooding. Furthermore, GI-based adaptation measures can play a significant role in managing climate change by absorbing greenhouse gases and enhancing resilience to climate risks.

Despite the potential of applying a GI approach in cities, traditional approaches continue to dominate urban planning and infrastructure development, in part because of the lack of systematic research on GI that can support decision-making and project implementation. Increasingly, officials and other stakeholders working in this field have called for a greater evidence base on GI projects and for practical guidance on implementing this unfamiliar approach.

In response to these calls and the growing interest in the GI approach, the past few years have seen a significant increase in South African research into GI, as well as the development of associated local guidelines and strategies (e.g. guidelines on sustainable urban drainage). This growing body of local knowledge and commitment has a particular emphasis on how GI can play a role in achieving water security and managing urban stormwater. For example, in 2014, the South African national government approved a Strategic Integrated Project on Ecological Infrastructure[3] for Water Security. This project aims to make strategic investments in ecosystems to enhance the functioning and health of the water networks which support the country's social, economic and environmental water needs. The project has paved the way for a regional-scale project in the uMngeni River catchment in KwaZulu-Natal. This project, the uMngeni Ecological Infrastructure Partnership, includes a number of municipalities and non-government stakeholders (who all have interests in enhancing water security in the catchment). This partnership has mobilised joint commitment to invest in the catchment's ecological systems in a way that integrates with the traditional infrastructure and built environment in the region. The deliberate framing of the initiative as an infrastructure imperative, rather than as a conservation project, has proved critical in building stakeholder support (Cumming et al., 2017).

South African cities have also begun deliberate engagement with strategic planning for GI, with both the City of Cape Town and the City of Johannesburg (CoJ) having acknowledged the strategic potential of GI in their respective urban contexts. Each of these cities is currently developing strategic documents or plans to support decision-making and planning for protecting, enhancing and maintaining existing green assets, and investing in new green assets[4] (Jackson, 2019), at a time when resource scarcity and growing urban populations have placed sharp focus on the importance of functioning ecological systems to support cities and human well-being.

This report contributes to the growing evidence base on applying a GI approach. It is a product of the ongoing research under the Gauteng City-Region Observatory (GCRO) Green Assets and Infrastructure project, and it builds on the foundations laid by the project's two preceding reports, which are described in the following section.

2 For more information about the CitiesWithNature initiative, see https://cwn.iclei.org/

3 Ecological infrastructure refers to the ecological or nature-based complement to grey infrastructure. This can include catchments rivers, wetlands and intact natural areas. Ecological infrastructure can be considered as a subset of GI.

4 At the time of writing, the GCRO was assisting the CoJ with the development of a Greening and Green Infrastructure Strategy.

This third report is the logical next step in a research journey which has progressed from establishing the theoretical foundations for, and conceptual underpinnings of, a GI approach to identifying what it would take to apply such an approach in the Gauteng City-Region (GCR), including potential opportunities and constraints. The aim of this report is to demonstrate the application of a GI approach in technical detail to further establish the case and speaks specifically to the practical aspects that might be of particular interest to project managers and government officials working in the field in the GCR.


Photograph by Christina Culwick

## Building the evidence

The GCRO Green Assets and Infrastructure project, which began in 2011, is designed to build the argument for, and the evidence base to support, the uptake of a GI approach in the city-region. The project has progressed through a series of phases – from the theoretical to the practical – that have systematically built towards a better understanding of the current state of GI in Gauteng, how government and other stakeholders value GI, and what is required for the adoption of a GI approach in urban planning and budgeting processes.

The project's first phase culminated in a report entitled *State of green infrastructure in the Gauteng City-Region* (Schäffler et al., 2013), which established the project's theoretical basis, assessed the physical state of GI in Gauteng, and investigated the extent to which municipalities understood, appreciated and valued GI in their planning and budgeting processes. This first report also included an exploration into how ecosystem services provided by GI could be financially valued in Gauteng. This report presented the argument that GI has significant potential to support government planning and infrastructure development in the GCR, and identified a range of issues for further interrogation for the theoretical possibility to become reality.

Accordingly, the second phase of the GCRO Green Assets and Infrastructure project was designed to further knowledge on how a GI approach could be implemented in the city-region. It responded in part to the significant data constraints faced in the first phase of the project and attempted to find innovative ways of building knowledge on GI. It was hoped this research phase would help government officials in Gauteng to coordinate around data collection and storage, particularly spatial data on green asset data. This phase of research adopted a transdisciplinary approach with the intention of co-producing a shared understanding of how to translate the theoretical approach into practical GI implementation. This was facilitated through the Green Infrastructure CityLab. The CityLab was a platform for engagement with government officials, academics and other stakeholders in Gauteng, and it facilitated a space to explore the opportunities and barriers to adopting a GI approach, and to co-produce knowledge and the direction of future research to support implementation in Gauteng (Culwick et al., 2019).

In parallel with the CityLab platform, and in response to the research areas identified in the first report, a series of studies were commissioned to draw on local South African experience in, and perspectives on, adopting a GI approach.

The first report's work on financially valuing GI in Gauteng revealed the need for deeper engagement with this subject. The first study in the second phase reflected on the City of Cape Town's experience of valuing ecosystem services, and engaged critically on the usefulness of full economic valuations of urban ecosystems in fostering support for GI within municipalities (Cartwright & Oelofse, 2016).

The second study demonstrated the importance of valuing GI, rather than the financial valuation thereof, as a means of encouraging the uptake of GI (Mander, 2016).

While the first two studies reflected on the particular arguments that are likely to gain traction in the South African context, the third study was more practical in its orientation, with a focus on the steps required to implement grey-green infrastructure projects as part of an integrated GI network in Gauteng (Dunsmore, 2016).

The Green Infrastructure CityLab engaged with these studies and used them to help to identify opportunities for implementing GI in Gauteng. The second phase of research was written up in a GCRO research report entitled *A framework towards a green infrastructure planning approach for the Gauteng City-Region* (Culwick et al., 2016). Based on the various studies and the CityLab engagements, the report concluded with recommendations for the third phase of the project, which proposed a set of case studies focused on areas of particular relevance for implementing GI in the Gauteng context. These studies form the basis of this, the third, report.

## Report rationale and overview

In the second phase of the GCRO Green Assets and Infrastructure project, the need to develop an evidence base to guide the uptake of GI in Gauteng became apparent. Accordingly, this report deliberately contributes to filling this research gap through three investigative studies, each exploring a different aspect of applying a GI approach. Each of these studies was conceptualised and shaped by the Green Infrastructure CityLab, and input from a range of key experts in the fields of ecosystem services evaluation and grey-green infrastructure design. The studies cover: the implementation of GI in an informal settlement context; a cost–benefit analysis of a GI project; and an exploration of the potential options for incorporating GI into municipal asset registries.[5] In addition, this report continues to develop GI mapping, a key aspect of the entire project to date.

Unlike the first two reports and project phases – which focused on conceptual and strategic arguments – this report is unapologetically technical. It is designed to be useful for officials and stakeholders working with, or interested in, the detailed implementation of GI projects and the institutional systems required to support them. As such, the report focuses on themes that are particularly relevant to the GCR, namely:

- Appropriate responses to rapid urbanisation and urban development;
- Stormwater management as an important aspect of adapting to, and mitigating against, climate change impacts; and
- Engagement with environmental justice and the restructuring of the post-apartheid city.

### Mapping GI in Gauteng

The report of the GCRO Green Assets and Infrastructure project's first phase presented an extensive set of maps and spatial analyses of existing green assets in Gauteng, thereby initiating discussion on different ways of assessing access to, and the distribution of, these assets. This spatial analysis revealed data quality and availability constraints, as well as the role of private and public perceptions and decision-making processes on green asset management as areas of concern.

In the second chapter of this report, Samkelisiwe Khanyile demonstrates how innovations in geospatial methods and the availability of new spatial datasets have been able to enhance the understanding of Gauteng's green assets and contribute to the argument for adopting a GI approach. The chapter builds on the work undertaken in the first two phases of the Green Assets and Infrastructure project, and it explores different elements of the GI network, including the distribution of green assets, the proximity to parks and the degradation of wetland ecosystems. A central theme is the unequal distribution of, and access to, green assets, which Khanyile argues compounds the existing social and economic inequality in the GCR. She also emphasises that a comprehensive spatial understanding of GI is a critical component for successfully implementing a GI approach.

### Implementing GI in informal settlements

Given that most GI research has emerged from the Global North, the GCRO's work deliberately engages in GI research to enhance the evidence base from, and relevance to, cities in the Global South. Most cities in the North are not growing particularly quickly, but are faced with significant challenges of retrofitting existing areas with GI solutions to help manage the negative implications of past development and reduce future risks, such as those associated with climate change.

In contrast, many cities in the developing world are growing rapidly and face the challenge of planning and developing infrastructure networks to meet the high and growing demand for services and amenities. The rate and scale of urban growth in the Global South, and the inability of local governments to meet housing and infrastructure

5 Each of the investigative studies has been edited from their original format to ensure coherence across the report.

needs, has resulted in the construction of large residential developments without formal housing and basic infrastructure networks. Without such networks, these areas face persistent challenges that undermine health and everyday well-being, and increased disaster risk. These informal areas have the potential to benefit significantly from alternative approaches to infrastructure development such as GI. However, one challenge of applying a GI approach in informal contexts is that the majority of existing solutions have been designed for 'developed' contexts and are difficult to implement in informal areas.

The GCRO's interest in GI for informal settlement contexts was piqued by a set of pre-feasibility studies undertaken in 2010 with the purpose of developing comprehensive stormwater networks in a number of informal settlements in Johannesburg. The costs of building traditional stormwater systems in these areas, as identified in these studies, were far beyond the CoJ's budget. This presented an opportunity to demonstrate to infrastructure planners and engineers the collective potential of a strategically planned GI network at a settlement scale. In response, the GCRO set out to develop a GI stormwater management intervention for an informal settlement without a formal drainage network. In the end, we were not able to secure the necessary external funding to undertake a project of this scale, but we were nonetheless able to facilitate research into what would be required to implement GI interventions in an informal settlement.

The second study in this report explores some of the opportunities for incorporating GI into Diepsloot, an informal settlement in the north of Johannesburg, to deal with surface water issues. This investigative study has two components, presented in chapters 3 and 4. In Chapter 3, Jennifer van den Bussche, Lerato Monama and Anne Fitchett present the principles that underpin sustainable urban drainage systems (SUDS) as a component of a GI network, and outline a set of formal SUDS interventions adapted for informal settlement contexts. In Chapter 4, the authors test some of these adapted interventions in Diepsloot, in partnership with a local organisation, the Water, Amenities and Sanitation Services Upgrade Programme (WASSUP) in Diepsloot. This project looked at how GI could contribute to creating or enhancing social amenities in the area while dealing with surface water and related health problems. The study deliberately drew on local knowledge and micro-scale solutions for addressing local surface water issues around communal toilets and washing areas, domestic wastewater disposal, and stormwater and flood risks. The study focused on two intervention sites involving action research with local residents.

The study identified significant potential for adapting 'formal' GI design options for informal settlement contexts. There was a marked improvement in the quality of the area immediately after completing the interventions. Although the study found small improvements in water quality as a result of the GI interventions, the authors also noted that if interventions were undertaken higher in the settlement's catchment areas greater improvements would result. The authors flag the necessity of community engagement and support for the success of any GI solution in informal settlement contexts.

*This report is designed to be useful for officials and stakeholders working with the detailed implementation of GI projects and the institutional systems required to support them*

## Cost–benefit analyses for GI projects

The GCRO Green Assets and Infrastructure project has, over the years, drawn on international examples from cities that were able to motivate for a GI approach through a cost–benefit analysis. Cities such as New York and Seattle have made compelling economic arguments focused on the cost savings as well as the avoided costs associated with taking a GI approach rather than a traditional grey infrastructure approach (City of Seattle, 2015; New York City Environmental Protection, 2010). Analyses that compare the costs and benefits of investing in the different options are critical for evidence-based planning and reducing the perceived risks associated with adopting new approaches. Government officials who participated in the GCRO's Green Infrastructure CityLab emphasised the importance of Gauteng-specific analyses of both the costs and benefits of GI projects. They stressed that such analyses should allow comparisons with traditional grey infrastructure approaches.

In Chapter 5, Stuart Dunsmore, Raishan Naidu and Marco Vieira conduct a detailed analysis of the costs and benefits associated with a flood relief scheme in Atlasville, a residential suburb in Ekurhuleni, Gauteng. This scheme is an example of the application of GI principles in combination with the traditional grey stormwater infrastructure. While the primary objective of the intervention was to alleviate flooding, additional objectives were incorporated into the study over time, including rehabilitating the river channel, improving the park area and enhancing ecosystem services along the Atlas Spruit.

The authors analysed and compared the scheme's real costs with the costs that would have been associated with a traditional stormwater attenuation scheme. The comparison includes both construction and maintenance costs, but also reflects on the benefits of each respective scheme on human well-being, ecosystem services and property values. The study concludes with a reflection on how the Atlasville flood attenuation scheme could have been improved had it included GI principles from the beginning of the project, and goes on to flag some of the key considerations for future GI projects.

## Incorporating GI into asset registries

The necessity of incorporating green assets into municipal asset registries became increasingly clear in the second research phase. Various stakeholders from the public and private sectors emphasised the importance of municipal asset registries in guiding urban infrastructure planning and budgeting for both investment and maintenance, all of which are critical for the successful implementation of GI. However, stakeholder insights revealed a lack of clarity regarding how this could be achieved in municipalities in Gauteng, and flagged this as an important area for future research.

Accordingly, the study described in Chapter 6 aims to demonstrate the requirements, and a potential methodology, for incorporating green assets into municipal asset registries. In this study, Gillian Sykes elaborates on the need to include green assets into municipal planning and accounting systems to support integrated planning and enhance the benefits of green assets at an urban or regional scale. The study sets out the current framework for municipal infrastructure planning, management and accounting, thus providing a necessary context for incorporating green assets into these systems. Sykes goes on to present some international examples of how green asset accounting is carried out in other contexts.

The study concludes by identifying a set of possible options for the South African context, as well as opportunities for, and obstacles to, incorporating green assets into municipal accounting and planning systems. It flags the importance of linking green assets to their associated ecosystem services to ensure the accuracy of locational information for each asset, and of housing the green asset data within the relevant department responsible for strategic planning. The insights from this study lay a foundation for future research into developing and utilising green asset registries to plan investment and maintain GI in Gauteng.


Photograph by Christina Culwick

## Conclusion

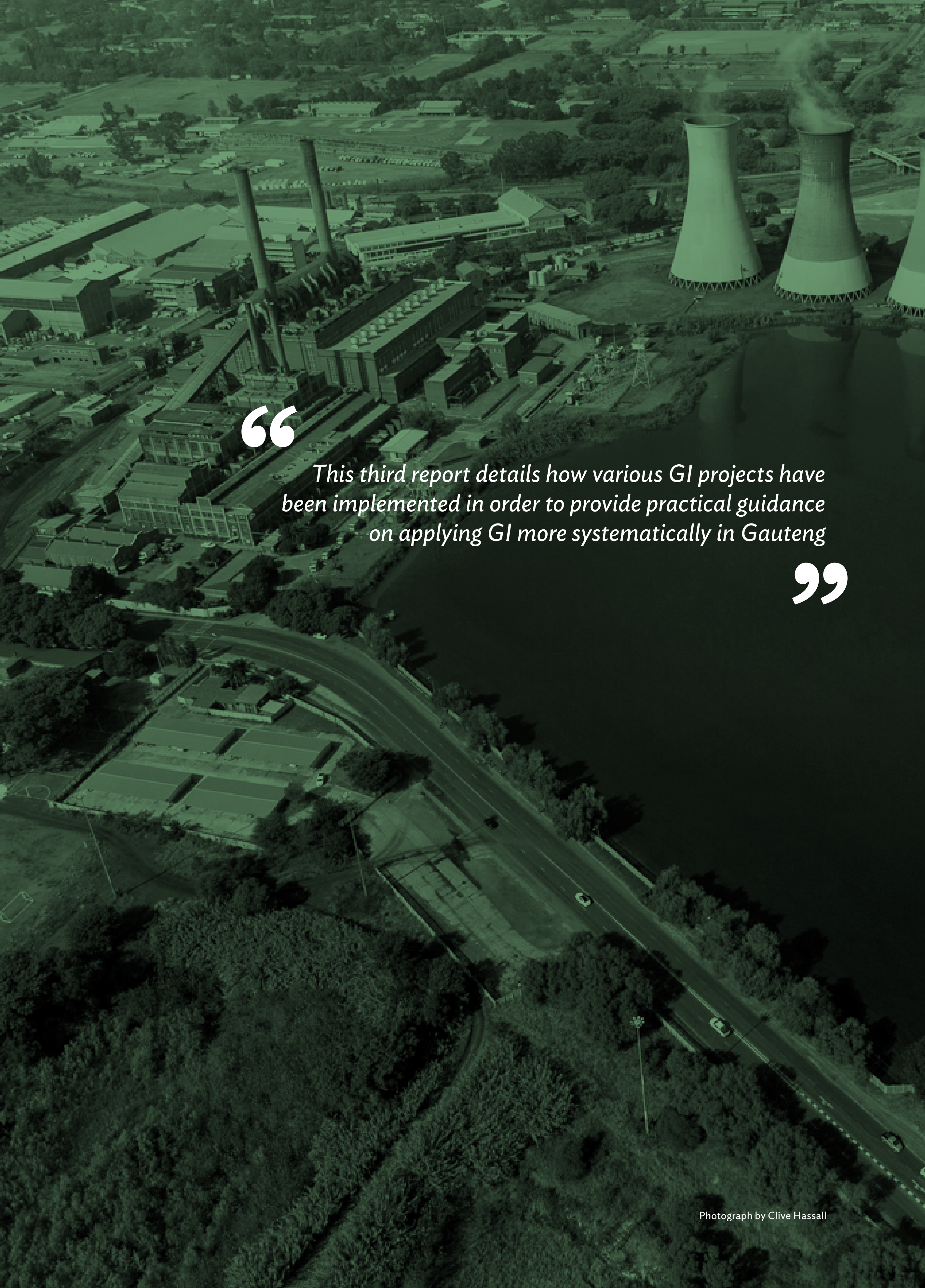
Gauteng faces a series of challenges related to rapid urbanisation and population growth, climate change, resource scarcity and reconfiguring urban space to be more equitable and inclusive. This GCRO research report highlights how GI can help tangibly improve the living conditions of people residing in informal settlements, and provides guidance for practitioners interested in similar projects.

In addition, the report demonstrates how GI can provide the same services as traditional infrastructure at a similar capital cost while also providing a range of additional benefits. Such findings are crucial for guiding future decision-making on investments in GI.

This report demonstrates how new spatial data and innovative analysis can provide greater insight into the current extent and status of GI. However, significant work is required to build the robust GI datasets capable of supporting the incorporation of green assets into municipal asset registries. The practical guidance on how green assets could be incorporated into municipal accounting systems further supports the argument for investment in, and maintenance of, GI in Gauteng.

This report, as the third in the series, builds on the foundations laid in the first two reports and phases of the GCRO Green Assets and Infrastructure project. This project has progressed from establishing the theoretical potential of GI for the GCR to exploring ways in which the theoretical GI approach could be applied in this context. This third report details how various GI projects have been implemented in order to provide practical guidance on applying GI more systematically in Gauteng.

The logical next phase of the project is to work with government towards building a strategic framework for implementing GI approaches in Gauteng.

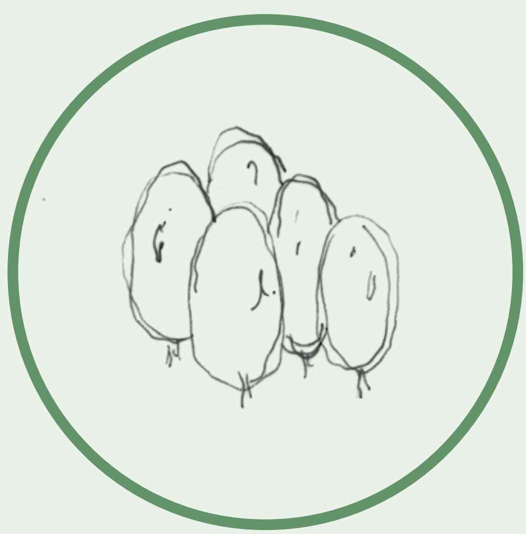


*"This third report details how various GI projects have been implemented in order to provide practical guidance on applying GI more systematically in Gauteng"*

Photograph by Clive Hassall

planted trees

green public & private spaces



# Chapter 2

# Mapping the inequity of green assets in Gauteng

*SAMKELISIWE KHANYILE*

## Key points

- **This chapter builds on mapping presented in the first report of the Gauteng City-Region Observatory (GCRO) Green Assets and Infrastructure project, *State of green infrastructure in the Gauteng City-Region* (Schäffler et al., 2013).**
- **The mapping conducted within this chapter combines comparable spatial data of varying formats and scales.**
- **This chapter comprises of three maps, each investigating the inequity of green assets and infrastructure across Gauteng through a different lens.**
- **The first map investigates the inequitable distribution of green vegetation. This map provides valuable insights on past green vegetation investments as well as prospects for future investments in green vegetation across the province.**
- **The second map investigates varying levels of proximity and accessibility of parks in Johannesburg while also providing insights on the implications of the use of different standards and administrative boundaries or units in equitable urban green space planning.**
- **The third map looks at the distribution of wetlands, as well as the degradation of wetland ecosystems in the province between 1990 and 2014.**
- **The mapping in this chapter uses alternative data analysis and visualisation techniques to illuminate new insights for the integration of green infrastructure (GI) into urban planning practices.**

## Introduction

Gauteng province has the fastest population growth rates in South Africa, resulting from both urbanisation and natural growth. However, while these trends contribute to the vibrancy of the Gauteng City-Region (GCR), they have been a challenge for post-apartheid spatial planning and development efforts. Rapid population growth has had a range of negative implications for Gauteng's natural environment as well as for the resources required to sustain the province. Furthermore, these negative environmental impacts are experienced unequally across the province.

Adopting a green infrastructure (GI) approach – a holistic urban planning approach deliberately incorporating natural and man-made ecological systems into infrastructure planning and development in a similar way to traditional grey infrastructure – has the potential to facilitate the transition to sustainable and equitable development. A GI approach can help ensure resilience to economic and societal changes, and empower urban planners to protect the natural resources that sustain communities and support biodiversity. Despite the potential benefits of adopting a GI approach, this has thus far only gained limited traction in the GCR (Culwick et al., 2016).

GI is eminently spatial and connected to social and economic systems. GI is also functionally and physically connected to the various elements of the urban environment. Thus, planning for GI would benefit from tools such as geographical information systems (GIS), which allow for the integration of various types of spatial data to represent green assets over a given space.

GIS are computer-based tools that enable the use, storage, management, manipulation, visualisation and analysis of information with spatial characteristics (Burrough & McDonnell, 1998). They are particularly useful for analysis of satellite remote sensing data on natural resources, detection of previous and current land uses, and prediction around the impact on natural resources of land use change (Duzgun et al., 2011). GIS also provide a systematic way of considering competing priorities of GI in urban spatial planning practices and in built-up environments where green spaces and assets are underutilised (Davies et al., 2006). A number of studies have been conducted internationally using GI mapping to promote the inclusion of GI in urban development planning. These studies have highlighted the many benefits of GI mapping, such as the quantification of green assets, the delineation of key ecosystems (Liquete et al., 2015), and the identification of ecosystem service needs and where these could be addressed using existing GI.

GIS-based mapping has been a key element of the Gauteng City-Region Observatory (GCRO) Green Assets and Infrastructure project since its inception, and has been used to build an evidence base for a GI approach.

The project's first report, *State of green infrastructure in the Gauteng City-Region* (Schäffler et al., 2013), included an extensive set of maps that illustrated and analysed the distribution of GI in the GCR; and the findings indicated that not only is access to GI inequitable, but also that access to spatial data on GI was very limited. Available datasets (especially across municipalities) were of differing origins – each using their own classification methods and data creation standards – and were of varying quality. This meant that the datasets were not comparable, hindering their ability to support decision- and policy-making, and, in turn, contributing to the slow traction and uptake of a GI approach.

As the first mapping of its kind in the GCR, the mapping presented in the first report was instrumental in laying the foundations for an argument around why a GI approach is critical for the city-region. But clearly more work needed to be done to build proper spatial data for more effective GI mapping and analysis.

Consequently, building on the first report (Schäffler et al., 2013), GI mapping in this chapter aims to contribute to the identification of various types of inequality in spatial distribution and access to GI across Gauteng. Identifying how green assets are distributed across the province is essential for providing an evidence base of areas in need of GI protection or investment, and, in turn, where current and future GI initiatives should be directed.

Adopting a multi-faceted approach to mapping the inequity of GI in Gauteng, this chapter uses spatial data of varying formats (which have become available since the publication of the first report in 2013) to map different types of inequality.

Two of the maps in this chapter use data derived from satellite imagery and have been analysed using satellite imagery processing techniques. Satellite imagery provides the possibility for deeper insights than most other GI mapping approaches aimed at quantifying green assets. Most data used in green asset and infrastructure mapping are areal data that aggregate values for an area. This kind of data does not account for the fragmentation of green assets. Satellite imagery has been used here to bridge existing issues with the inaccessibility of comparable and consistent data for accurately mapping green assets. Mapping based on satellite imagery proves to be very helpful in revealing the complexity and characteristics of GI distribution and change in rapidly urbanising environments such as the GCR.

The chapter considers inequality of GI through three lenses: the distribution of green vegetation; proximity and accessibility of parks; and the unequal distribution of, and change in, wetlands – a critical ecosystem. The chapter provides evidence that these inequalities, many of them historical, are being exacerbated, since not enough provision is being made to preserve or extend existing green assets, and key ecosystems such as wetlands continue to be degraded. The chapter concludes with a discussion on how these innovations in the spatial visualisation on GI contribute to building an evidence base for the further adoption of a GI approach in the GCR.

## Assessing the distribution of green vegetation across the GCR

Gauteng was originally a grassland biome (Bredenkamp et al., 2006) prior to the discovery of gold along the Witwatersrand mining belt. Grassland biomes, typically characterised by smaller trees and shrubs, provide ecosystem services such as carbon sequestration and capture, and play an important role in the hydrological cycle by reducing immediate runoff and storing it on the surface or as groundwater (Egoh et al., 2011; Kotze & Morris, 2001). However, since the discovery of gold, Gauteng has been characterised by rapid spatial transformation and urban development. This has seen the conversion of grassland in many parts of the province into impervious surfaces (roads, parking lots, pathways, pavements, rooftops, etc.), resulting in a range of negative implications for the natural landscape and leaving it in urgent need of protection and preservation. In other parts of the province, the transformation of grasslands has been accompanied by the planting of alternative vegetation (often greener and larger tree species not native to South Africa) and the creation of green public spaces, circumventing some of the negative impacts of urban development.

Green assets in urban areas such as the GCR provide a range of ecological services such as shade and temperature regulation, carbon capture and stormwater attenuation. As such, they can help clean the environment and enhance environmental health, improve well-being, and aid in the functioning of infrastructure and service delivery (Culwick et al., 2016). The mapping in this section investigates the presence of green vegetation across the province.

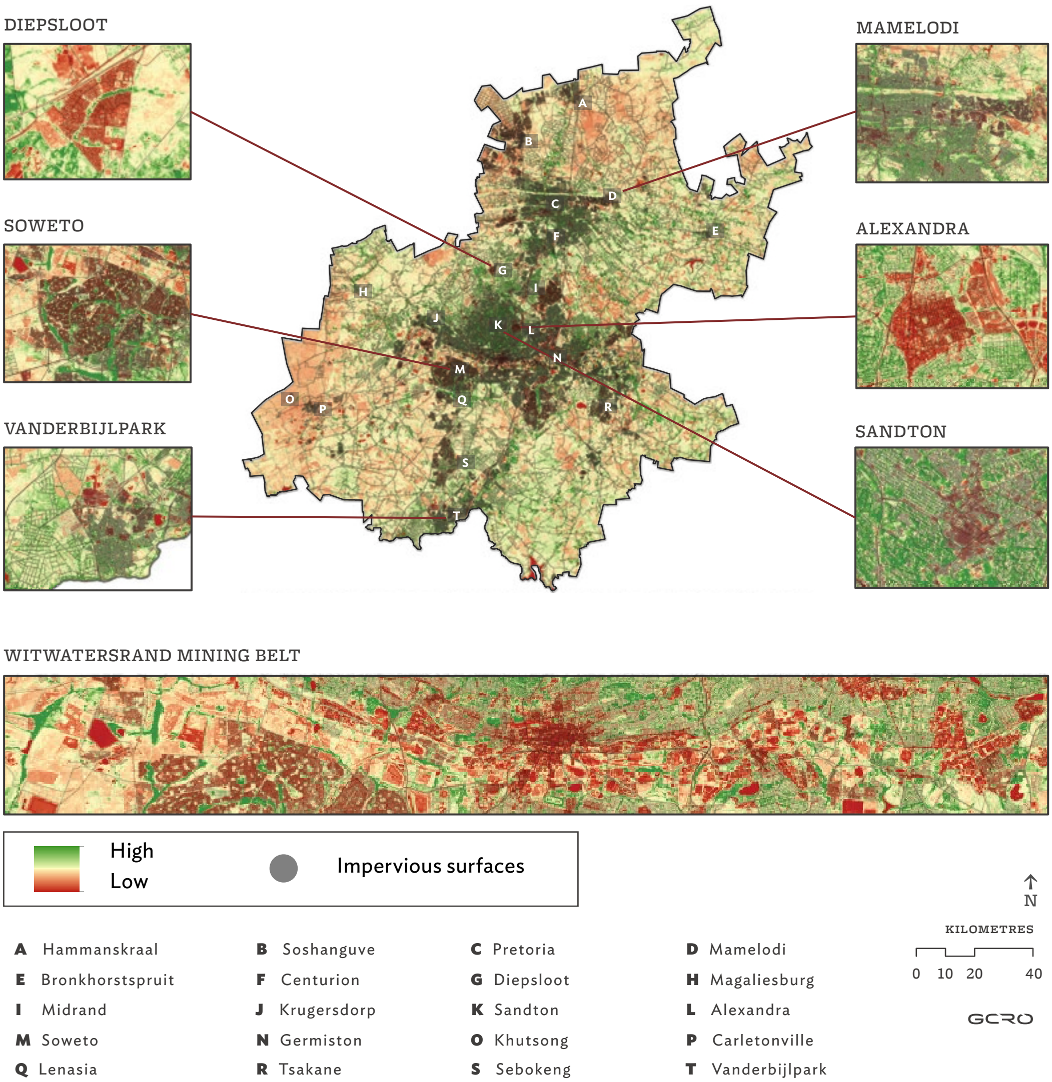
Map 2.1 uses satellite imagery (Landsat 8 Enhanced Thematic Mapper Plus, taken at a resolution of 30 m) and applies a normalised difference vegetation index (NDVI) to generate an image of the greenness of vegetation in Gauteng. Healthy green vegetation converts light and carbon dioxide to produce oxygen during photosynthesis, and thus the map also serves as a proxy for ecosystem services across the province. NDVI measurements range from –1 to 1, with higher values indicating greener plants, greater plant health and potentially a higher likelihood of greater ecosystem productivity. The NDVI quantifies the greenness of vegetation on satellite imagery by measuring the difference between red light (which is absorbed by vegetation) and near infrared (which is reflected by vegetation), different measures of which are found in green vegetation and grassland. Grassland species typically have less chlorophyll, and therefore emit radiance differently to bigger and greener vegetation such as trees. This has implications for how grassland areas are registered by satellites and consequently recorded in satellite imagery (Weber et al., 2018).

Map 2.1 uses shades of green and red to represent vegetation across the province. Green, on one end, indicates the presence of green vegetation. Orange to red, on the other end of the scale, corresponds to grassland (on the medium to low spectrum) and open areas where green vegetation is low. Orange to red also includes areas of unhealthy vegetation, bare rocks and underlying soil (Sun & Kafatos, 2007). The areas mapped in grey indicate impervious surfaces, concentrated mostly at the core of the province, which is mainly characterised by urban land use.

This map shows that the highest NDVI values are concentrated at the core of the province, as well as in suburban areas, which were typically areas for white people under apartheid. Wealthier suburbs, such as Bryanston, Sandton and Vanderbijlpark have high NDVI values, indicating significant tree coverage in private gardens, street pavements, well-maintained parks and irrigated agriculture. These areas benefit from a range of ecosystem services associated with leafy green vegetation. As with impervious surfaces that are relatively devoid of vegetation, these highly 'green' areas are indicative of the transformation of Gauteng from grassland into the urban environment. Although these planted features provide important ecosystem services, they often require more water than the naturally occurring grassland vegetation.

**Map 2.1:** Green vegetation distribution map of Gauteng using an NDVI. The map insets on either side zoom into different parts of the province, i.e. Diepsloot, Soweto, Vanderbijlpark, Mamelodi, Alexandra and Sandton.

**DATA SOURCES:** MDB (2011a) Gauteng Province boundary; USGS (2016) Landsat 8 Thematic Mapper Plus; GTI (2014a) 2.5 m Land Cover; Gauteng Department of Roads and Transport (2010) Roads




Note: The author of this map is Samkelisiwe Khanyile. This map was previously used as a GCRO Map of the Month and the accompanying text was authored by Samkelisiwe Khanyile and Gillian Maree (Khanyile and Maree, 2017). The text has been changed in this chapter, with the assistance of Christina Culwick.

The smaller map insets on either side of the central map zoom into different parts of the province, revealing inequality in the distribution of green (planted) vegetation across Gauteng. Areas where mostly previously disadvantaged population groups reside, such as Alexandra, Soweto, Mamelodi and Diepsloot (see respective map insets in Map 2.1), have very low NDVI values, indicating the predominance of bare soil, impervious or hard surfaces, grass and sparse bushes. This map is indicative of the disparities of the apartheid planning legacy, which saw the provision of limited public spaces in areas where black people lived. Over time and with the expansion of these areas, limited public space provision has persisted in older and larger townships such as Soweto (Findley & Ogbu, 2011; Schäffler et al., 2013). This trend continues in other townships which were developed after apartheid, such as Diepsloot. Many of these new areas have developed rapidly due to the demand for land, and are characterised by informality. Consequently, these areas do not have adequate green assets or spaces and thus do not benefit from the wide range of ecosystem services available in more affluent areas. This highlights a 'double' disadvantage, where higher levels of poverty and poorer access to traditional infrastructure and services are associated with lower levels of access to ecosystem services provided by green vegetation. This combination results in a lower potential quality of life for people in township areas.

Further to this, areas such as Soweto are characterised by a mostly flat topography (Manga et al., 2019), and the prevalence of impervious surfaces. These impervious areas cause a reduction in the area where infiltration to groundwater can occur, which, when coupled with the lack of stormwater infrastructure and close proximity to water sources or flood lines, results in higher risk and vulnerability to flooding disasters during heavy rainfall. Lower coverage of vegetation also increases the likelihood of erosion of topsoil during drought seasons and, in turn, the risk of health impacts from airborne particulate matter.

In Gauteng, the NDVI is important for highlighting the impact of past and current land uses and identifying areas where land rehabilitation efforts should be focused. The long strip at the bottom of the map zooms into the Witwatersrand mining belt, which cuts across the province from east to west, and is characterised by very low NDVI values. This is particularly true for areas used as facilities for the disposal of mine residues, which in some instances are radioactive and affect soil properties, therefore making them more unsuitable for vegetation growth, further compounding the problem. Although some vegetation exists around these areas as a consequence of ongoing and past rehabilitation attempts instigated by the Mining Rights Act of 1967 (Khanyile, 2016; Kilian et al., 2005; Mubiwa & Annegarn, 2013), green vegetation in these environments is limited. Such areas are characterised by damaged and degraded ecological functions, and consequently do not benefit from potential ecosystem services that could help improve environmental quality, such as the attenuation of runoff and the infiltration of water, as well as the breaking down of organic compounds in contaminated environments (Davis et al., 2002).

This map demonstrates the inequitable distribution of green vegetation across Gauteng. It also indicates where green vegetation investment has been focused in the past as well as the impact of the apartheid spatial planning legacy on the resultant distribution of public spaces, green assets (such as trees) and space which could conceivably be vegetated. Similarly, the map shows the unequal distribution of the negative externalities of past land uses – in areas such as the Johannesburg central business district (CBD), Krugersdorp and Khutsong – where the quality of the soil in these previously mined areas may limit the presence and the quality of vegetation compared with the surrounding areas.

Map 2.1, and others using similar mapping techniques, are imperative for informing urban planning and infrastructure development policies. They serve as a proxy understanding for where negative implications of urban growth are predominant, and where investments in GI are necessary to counteract them. In particular, they are useful for identifying where limited or poor quality green assets are coincident with a lower quality of life for already disadvantaged groups. While providing useful insights on the inequity in the distribution of green vegetation across the province, the map does not show accessibility to these or similar green assets. The next section investigates the accessibility of green assets in the City of Johannesburg (CoJ).

## Proximity and accessibility of parks in the CoJ

In recent decades, considerable evidence has accumulated highlighting that green space positively contributes to the liveability of urban environments and an improved quality of life for residents (e.g. Kondo et al., 2018; Mensah et al., 2018; Zhang et al., 2017). Parks and green spaces provide access to recreational spaces, increase property values and provide a range of ecosystem services, including micro-climate regulation (such as reducing heat stress), flood control, air purification and noise reduction (Bolund & Hunhammar, 1999; Li & Pussella, 2016). Thus, green space provision and access is an important component of delivering urban services and infrastructure, and has become critical to public health in urban environments (Sister et al., 2010).

Considering the many benefits of green spaces, unequal access to urban parks and green spaces, particularly for the urban poor, has piqued the interest of many a researcher interested in how existing inequities in access to key natural and environmental assets in urban environments can be bridged (e.g. Agyeman et al., 2002; Sister et al., 2010; Walker, 2009; World Health Organization [WHO], 2010). Standards have been established – both internationally and locally – to ensure consistency and certainty in urban green space planning (Maryanti et al., 2016). These include the standard of a minimum of 9 m$^2$ of urban green space per person by the WHO (WHO, 2010), and the standard of 2 ha of green space per 1 000 people in Johannesburg (CoJ, 2012, in Schäffler et al., 2013).

These standards aim to ensure sufficient access to green space, and their associated ecosystem services, for all urban residents (Calderón-Contreras & Quiroz-Rosas, 2017; Turner, 1992). It does need to be noted, however, that these standards differ over time and spatial scales (Schäffler et al., 2013). For instance, a city may meet an overall standard on average, measured per capita or per 1 000 people, but specific areas within the city may be in severe deficit while other areas have a surplus of green space. It may also be difficult to identify which areas fall below a certain threshold and, in turn, where to direct green space investment. In addition, some standards prioritise quantitative criteria which only focus on physical accessibility or the amount of green space available to a certain number of residents rather than on the quality of the available green space. Nevertheless, in theory, these standards provide an opportunity to compare and benchmark equitable access to parks and other green spaces, and thereby facilitate a reduction in inequality through more targeted investments.

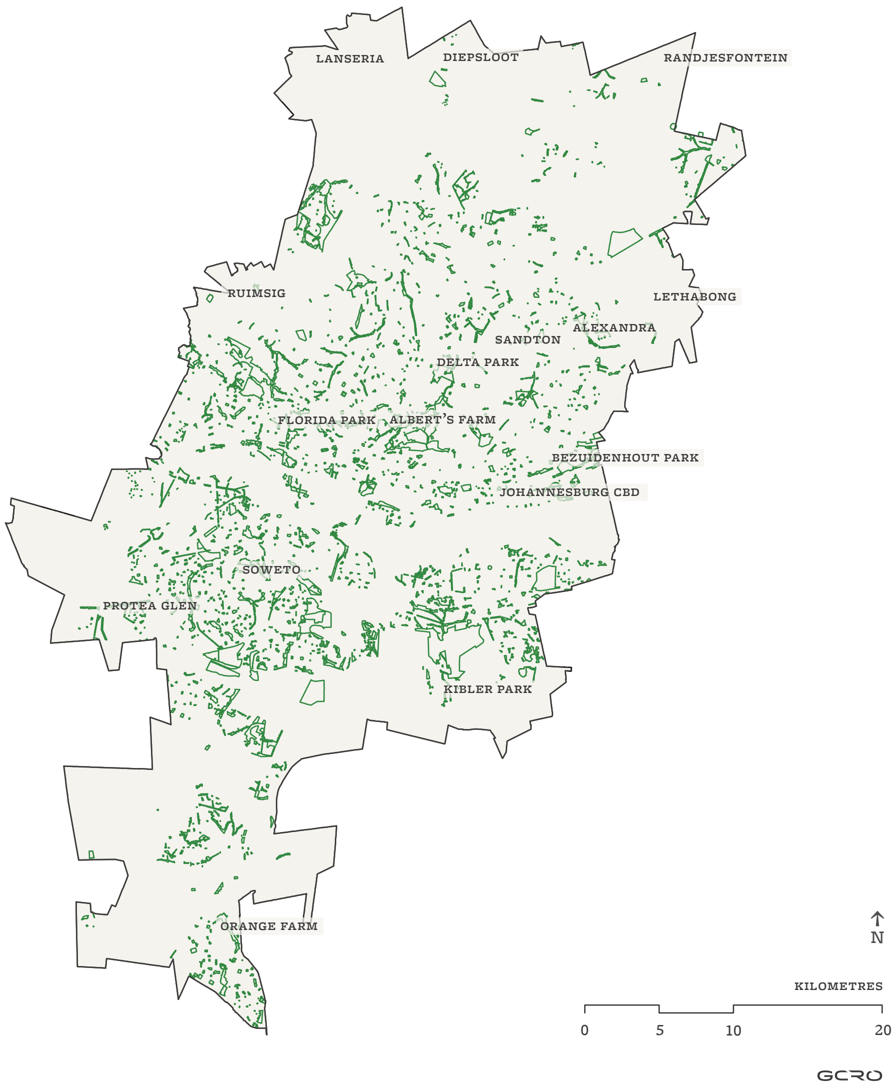
Map 2.2 shows the distribution of Johannesburg City Parks and Zoo-owned land in the CoJ. Map 2.3, Map 2.4 and Map 2.5 investigate the application of three different standards for parks and green space proximity and accessibility in the City. These maps assess the benefits as well as drawbacks of each of these standards, and consider the varied outcomes potentially implied by the use of these differing standards in urban green space planning.

Map 2.2 shows that parks are not equally distributed across the CoJ; the northern- and southern-most parts of the City, in areas around Lanseria, Diepsloot, Randjesfontein, Ruimsig, Lethabong and Protea Glen, have fewer parks compared with the more central parts of the municipality, with the exception of the immediate surroundings of the Witwatersrand mining belt. Map 2.2 also shows that the parks across the city vary in size.

*Green space positively contributes to the liveability of urban environments*

**Map 2.2:** Spatial distribution of parks across the CoJ

**DATA SOURCES:** MDB (2011b) City of Johannesburg municipal boundary; CoJ (2017) Johannesburg City Parks and Zoo Land Data




City Parks and Zoo land (as at 2017)

City of Johannesburg

Map 2.3 and Map 2.4 investigate park proximity, where proximity refers to the geographical distance between people and parks (Boschma, 2005). Map 2.5 investigates the accessibility of parks, where accessibility refers to the possibility of reaching a desired location over a certain distance (Yigitcanlar et al., 2007), in this case, relying on the density of the street network that enables people to reach parks. All three maps are based on different administrative boundaries or units and each uses different accessibility standards that prioritise different criteria. This has an impact on the visual outputs, as well as on the interpretations that can be drawn.

Map 2.3 shows the initial mapping of park proximity in Johannesburg conducted in the GCRO research report, *State of green infrastructure in the Gauteng City-Region* (Schäffler et al., 2013). The first in this series of three maps applies an international benchmark of 4 ha of quality public open space per 1 000 residents at the ward level based on the centroid of public parks and open spaces (CoJ, 2012, in Schäffler et al., 2013; Johannesburg City Parks and Zoo, 2012, in Schäffler et al., 2013). It shows that a majority of the wards in the city have below the prescribed 4 ha of park access, particularly in the far southern and northern parts of the municipality. Only a few wards in the city have enough park space on this measure, but these are likely wards with a low population density, or with rather large parks.

The second and third maps in Map 2.3 do further analysis using the Statistics South Africa (StatsSA, 2012) small area layer (SAL),[1] where each SAL typically combines a few enumeration areas (EAs).[2] By mapping the 2011 population to this very fine geographic scale, it is possible to ascertain the number of people within and outside a 750 m buffer of public parks. The number of people within each SAL that is within a 750 m buffer of a park is represented in shades of green (the higher the number of people, the darker the green), and the number of people in SALs outside of the 750 m buffer is shown in shades of red. This mapping shows more residents in close proximity to parks than the first one.

Map 2.4 is a continuation of the initial analysis presented in the GCRO's first GI report (Khanyile, 2017), and uses the African Green City Index, which recommends a minimum of 60 m$^2$ of green space per person (Economist Intelligence Unit & Siemens, 2012). This mapping exercise considers proximity to parks in the CoJ. Map 2.4 shows parks per capita in the CoJ at the SAL level, and represents areas falling below the prescribed 60 m$^2$ per person in red, and areas falling above this threshold in orange, yellow or shades of green. Map 2.4 indicates that most areas – including Alexandra, Soweto, Diepsloot, Orange Farm, the Johannesburg CBD, Randjesfontein and Protea Glen – typically have access to less than 60 m$^2$ of park space per person. These are mostly areas with poorer communities. By contrast, there is typically 60–100 m$^2$ of parks per person for those living in areas such as Florida Park, Ivory Park and Fleurhof. The map also indicates that residents of many areas at the periphery of the municipality – in areas such as Kibler Park, Lanseria, Lethabong, Magaliesburg and Bezedenhout Park – have more than 100 m$^2$ of park space per capita. However, it is important to note that many green spaces on the periphery are on private small holdings, estates, farms and protected areas, where public access is restricted.

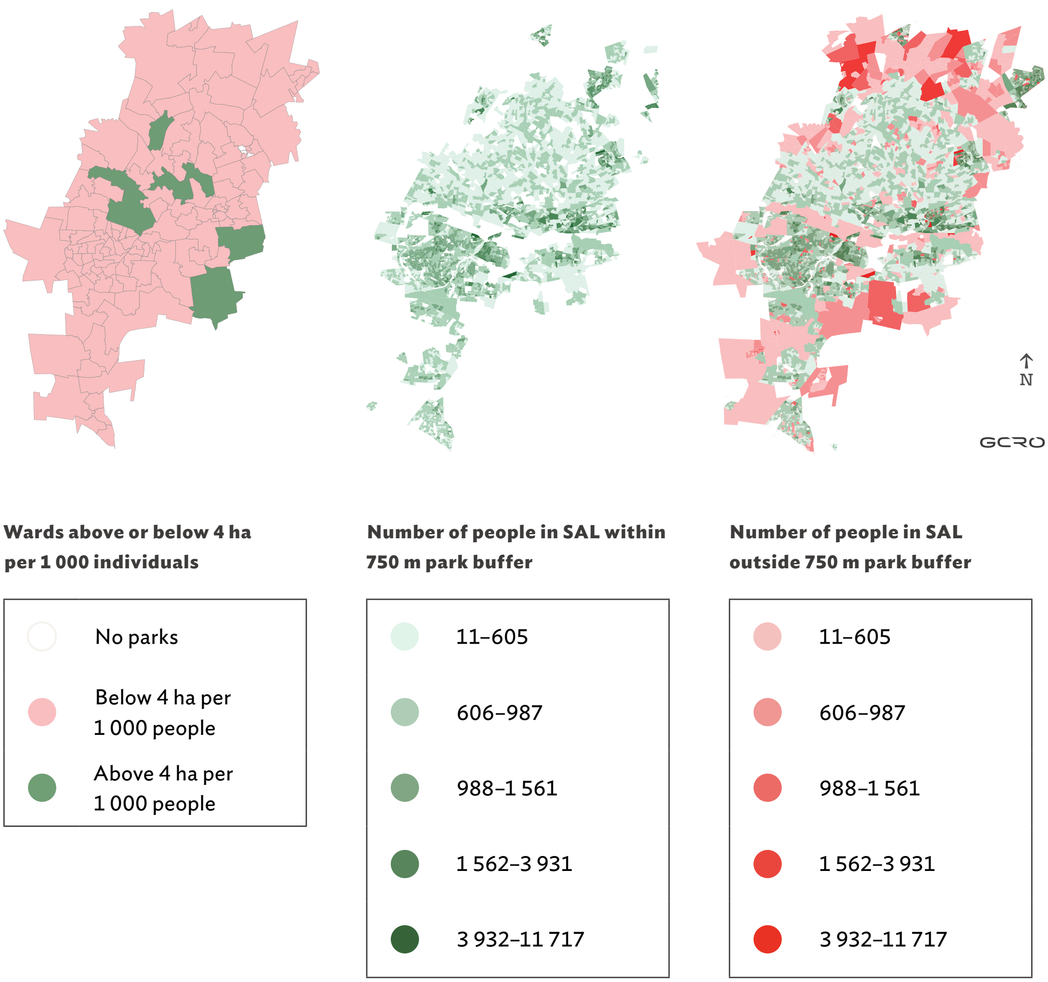
## *A majority of the wards in the city have below the prescribed 4 ha of park access*

1 Not all parts of the Gauteng province have been divided into SALs, hence the white patches on the subsequent maps.

2 EAs are the smallest geographical unit (piece of land) into which the country is divided for enumeration purposes. These geographical units contain between 100 and 250 households (StatsSA, 2012).

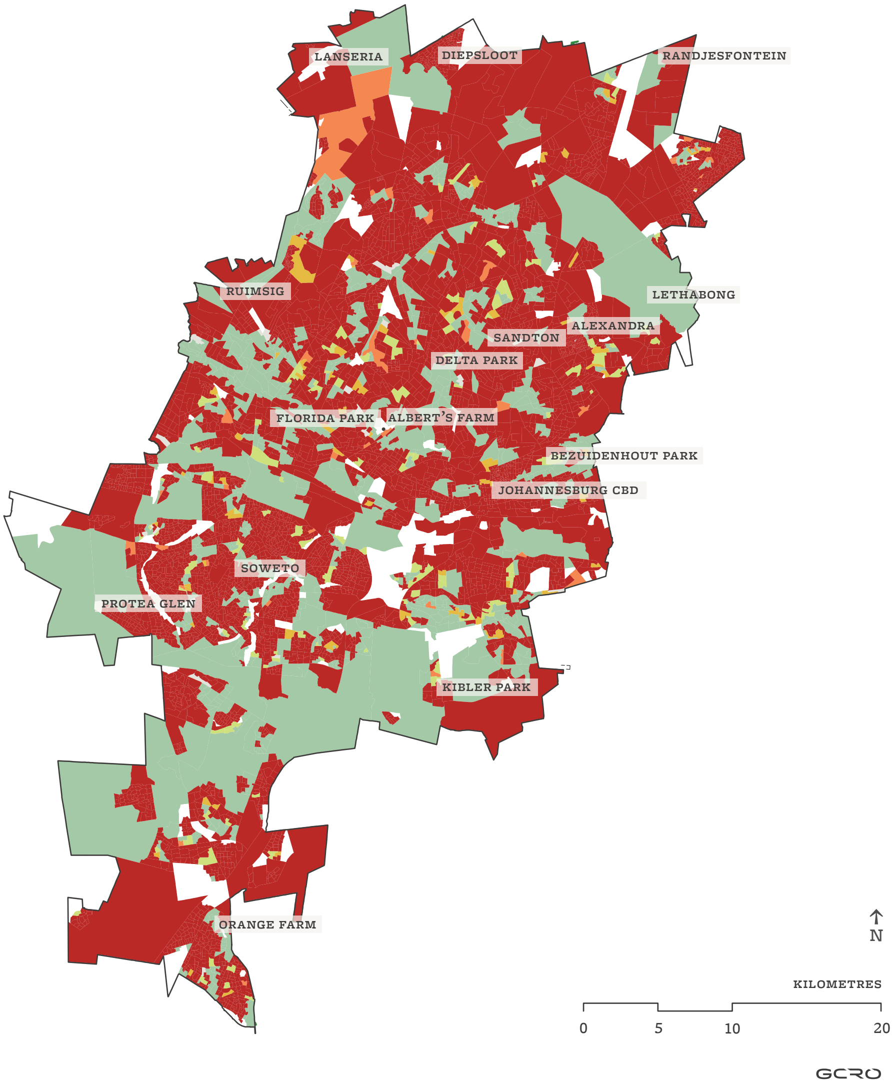
**Map 2.3:** Proximity to parks in the CoJ. The map on the left shows park proximity in the CoJ based on the City's prescribed 4 ha per 1 000 people standard. The map on the right shows an overlay of the previous map with the number of the City's residents within a 750 m walking distance to public parks.

**SOURCE:** Adapted from Schäffler et al. (2013)



**Map 2.4:** Parks per capita per SAL unit, based on the African Green City Index

**DATA SOURCES:** MDB (2011b) City of Johannesburg municipal boundary; StatsSA (2011a) Small Areas Layer; Economist Intelligence Unit & Siemens (2012) 60 m² Green Space Standard; CoJ (2017) Johannesburg City Parks and Zoo Land Data




**Square metres of green space per capita (per SAL)**

| | | | |
|---|---|---|---|
| 0–59 | 60–65 | 66–72 | 73–75 |
| 76–100 | 101–60 207 | City of Johannesburg | |

Map 2.3 and Map 2.4 provide differing insights on what proportion of Johannesburg residents live in close proximity to parks. Soweto is a case in point, where the two maps present very different results. Map 2.4 suggests that Soweto has low park access, while Map 2.3 shows Soweto as having high park access. The differences in the two maps can be attributed to the use of different standards and areal units, i.e. the use of SALs in Map 2.4 versus the use of subplaces in the first map of Map 2.3. Most importantly, Map 2.3 shows that while many SALs (with very high population counts) are within 750 m of a park, the very high population densities in Soweto mean that a large number of people share relatively little green space on an area per person basis.

Despite the insights these two maps provide on people's proximity to parks in Johannesburg, they do not provide sufficient understanding of the accessibility of parks given the many other factors that affect reachability or usability, such as access, routes to, or the private ownership of, green space.

The next map in this section, Map 2.5, draws on recent advancements within the CoJ to investigate park accessibility. The municipality recently adopted the Spatial Development Framework 2040 (CoJ, 2016), which places an emphasis on city planning and development efforts to enhance accessibility and density in key nodes across the city. This 'nodal policy' aims to encourage sustainable development, promote efficient and equitable use of natural resources (Haaland & Van den Bosch, 2015) and transform the legacy of spatial inequality inherited from apartheid (CoJ, 2016).

Access to city parks and other green spaces is particularly important in densifying cities, which are very built up, have high population densities, and are often characterised by limited green and open spaces, especially for poorer residents who cannot afford private gardens. If planned in combination with the traditional grey infrastructure network, parks and green spaces in compact urban spaces can provide multi-functional assets that support and reduce the burden on traditional infrastructure. Therefore, it is of utmost importance for green space investment to be directed towards areas of planned densification and development.

The CoJ's recent Draft Nodal Review (CoJ, 2018) applied a newly established urban development model as a basis for assessing current levels of accessibility to inform decision-making on where investments are needed. Map 2.5 describes the park accessibility maps derived by the CoJ for its Nodal Review, as developed by Weakley (2018). Its innovation is to consider the accessibility of parks based on the CoJ road network, as in most cases there needs to be a road to get to the vicinity of the park.

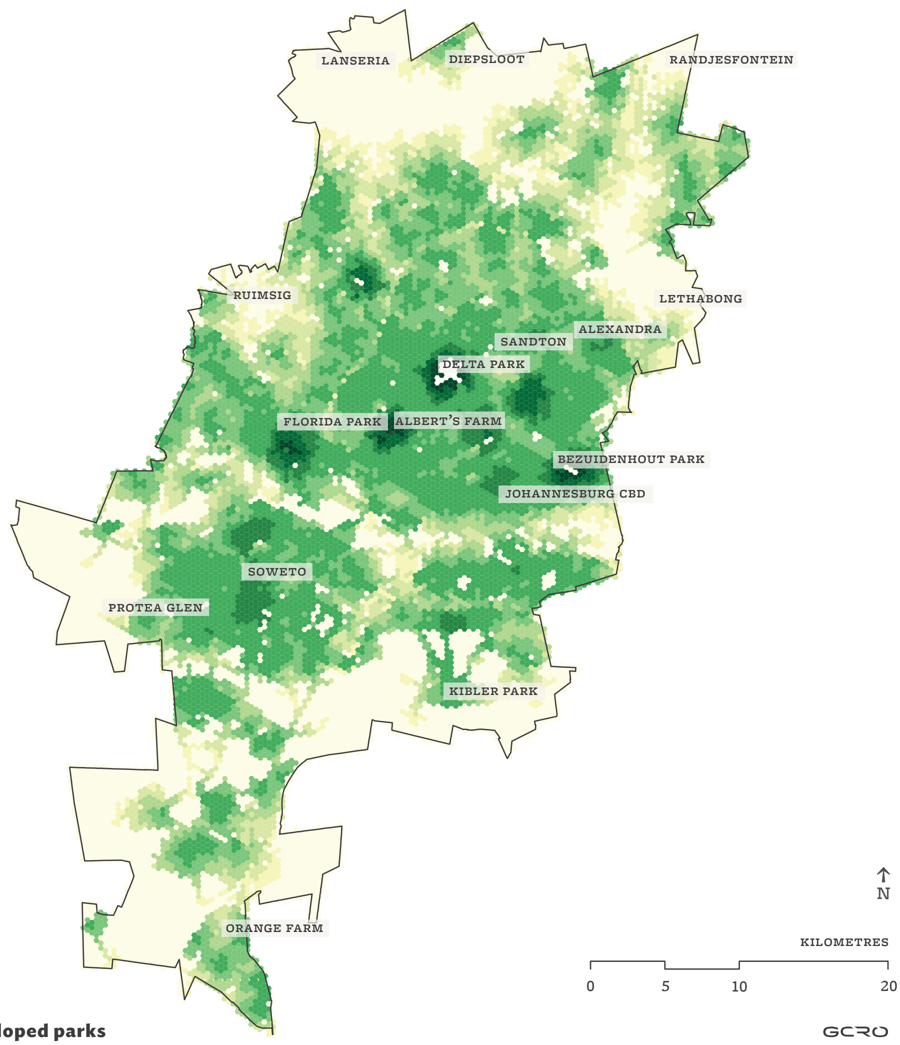
The Nodal Review's urban development model uses 400 m by 400 m hexagons[3] to measure access to essential amenities and establish a range of accessibility indices (CoJ, 2018). This deviates from the usual measurements which utilise administrative boundaries such as wards, subplaces and SALs, all of which are of varying sizes and therefore produce different results. Further to this, the model uses the street network to calculate a 1 km walkability score and a 2 km service area score to calculate accessibility from the centre of each hexagon. This is a step further than the usual methods, which primarily look at proximity and accessibility in terms of physical location. The CoJ applied the method to establish accessibility scores for a range of urban functions and amenities – including schools, health services, places of employment and parks – for each hexagonal area.

In calculating park accessibility, the CoJ model takes into account all land that is owned and managed by Johannesburg City Parks and Zoo, including both developed and undeveloped parks (CoJ, 2018). The park accessibility index for all hexagons covering the city ranges from 0 to 1, with 0 having the worst accessibility and 1, the best. Map 2.5 shows the accessibility of developed parks across the CoJ using a colour ramp of light yellow (0) to dark green (0.90) (CoJ, 2018).

3 400 m by 400 m hexagons are utilised in this model as they are considered easily walkable units (CoJ, 2018).

**Map 2.5:** Park accessibility in the CoJ, based on the City's Draft Nodal Review (2018)

**SOURCE:** Adapted from Weakley (2018)
**DATA SOURCES:** MDB (2011b) City of Johannesburg municipal boundary; CoJ (2017) Johannesburg City Parks and Zoo Land Data; CoJ (2018) Corporate GIS: Draft Nodal Review Park Index




**Access to developed parks**

| | |
|---|---|
| 0.00–0.11 | 0.11–0.20 |
| 0.21–0.30 | 0.31–0.40 |
| 0.41–0.50 | 0.51–0.60 |
| 0.61–0.70 | 0.71–0.80 |
| 0.81–0.90 | City of Johannesburg |

Low park accessibility can be observed in the peripheral areas in the city and in low- to middle-income areas such as Lanseria, Lethabong, Randjesfontein and Protea Glen. By contrast, some areas, mostly in the central and northern parts of the city, have a high park accessibility. These areas tend to cluster around the City's large parks, such as Albert's Farm, Florida Park, Bezuidenhout Park and Delta Park. Interestingly, some large parks, such as the Johannesburg Botanical Gardens, do not have good accessibility around them because of the low road density in the surrounding areas.

It needs to be noted that the map is based exclusively on CoJ-owned developed green assets. There are also undeveloped green spaces such as ridges that are utilised in various ways. In addition, there are private, access-controlled green spaces such as private nature reserves, golf courses and country clubs, typically in prime real estate areas. In these instances, poor accessibility is not a function of a lack of green space or the density of a road network, but is rather due to the fact that these assets are reserved for those who can afford to pay for their use, or who live within these privatised spaces. Restricted access to these privately controlled spaces poses a significant limitation in terms of ensuring that the recreational benefits of GI are equitably shared. However, they do still provide wider public benefit by way of their other ecosystem services.

The park accessibility index (Map 2.5) is innovative in its use of non-standard boundaries of analysis in combination with the street network, to provide a nuanced measure of accessibility to parks. Of course, a strong argument could be made that 2 km cannot be considered 'walkable', as many standards in the United States, Canada, Australia and New Zealand set a maximum walking distance of 400 m (Walker, 2011). The model is also based on calculating, using the road network, the accessibility of various amenities in each hexagon. In this calculation, however, the population of each hexagon is not taken into account. As a result, it does not show accessibility based on how the area of park space is shared on a per capita basis, and so the result ends up looking more like the maps in Map 2.3 than Map 2.4.

Furthermore, these maps do not provide insight into the quality or actual use of the various parks in the City. Despite this, this park accessibility index is a significant improvement on the previous analyses related to park access. The calculations could be further strengthened by the inclusion of a range of other tangible and non-tangible factors which impact accessibility, such as population densities, the physical health or socio-economic characteristics of surrounding communities, and the availability of other resources or assets such as cars, bicycles or public transit that could be used to access parks.

Overall, the maps presented in this section provide useful insights on varying levels of proximity and accessibility to parks and green spaces. The maps here are based largely on parks that are designed and built into the urban fabric. However, it is also important to plan around green assets which are naturally occurring, such as wetlands. Accordingly, the next section investigates the state of wetlands across Gauteng, with an emphasis on their loss and degradation.

*These maps are based largely on parks that are built into the urban fabric; however, it is also important to plan around naturally occurring green assets, such as wetlands*

## Degradation of green assets

The growing demand for land to support urban and infrastructure development means that essential aspects of the GI network, such as wetlands, are constantly under threat. Wetlands are crucial for the functioning of broader ecological processes as they provide a range of critical ecosystem services to biodiversity, hydrological systems, as well as human well-being (Hu et al., 2017). Some 170 countries globally have signed a treaty – the Ramsar Convention – thereby committing to protect and manage wetlands sustainably (Frazier, 1999). Nevertheless, despite the acknowledged importance of wetlands, these ecosystems continue to face damage and destruction across the globe.

In some instances, wetland transformation may be due to urban development processes such as building of roads or houses. In other instances, wetlands are degraded by water drainage – often from development upstream – or the introduction of invasive species, such that they dry up or become overgrown and end up indistinguishable from surrounding natural land uses. Wetland transformation to natural land uses has been noted in a range of studies (e.g. Gibson et al., 2018; Wu et al., 2000; Zhang et al., 2011).

Where wetlands are shrinking and healthy wetland functioning is being undermined, the valuable ecosystem services they provide are impacted. Global literature (e.g. Day et al., 2003; Mitsch et al., 2012; Showalter et al., 2000; Yang et al., 2016) points to a decline in water quality in surrounding water systems when wetlands and the ecosystem services associated with them, such as nutrient reduction and in particular nitrogen removal, are lost or degraded. The Rietspruit catchment is a local example. According to Showalter et al. (2000), the introduction of low-cost, formal residential developments in the area led to a degradation of this wetland system due to increasing levels of pollution, contamination and infilling. In turn, there was a significant decrease in the water quality of rivers feeding from the four wetlands in the catchment.

The maps in this section (Map 2.6 and Map 2.7) provide a change detection analysis using remotely sensed land cover data to identify the land uses that wetlands have been transformed into across Gauteng between 1990 and 2014. Mapping wetland transformation or degradation is imperative for identifying which should be protected, which will require rehabilitation interventions to correct for damage, and where there might be a need to compensate for a loss of function through investing in traditional infrastructure.

Change detection studies that systematically correlate and evaluate satellite images of the same area at different times have been used to analyse transformations in different land uses (Singh, 1989). Land cover data have been used continuously as the foundation for GI change detection mapping as they provide a consistent depiction of land features, and are generally comprised of small cells (or small geographical units) which show the boundaries and fragmentation of land features with a higher accuracy than areal data (Hoctor et al., 2000; Wickham et al., 2010). This mapping uses GeoTerra Image (GTI) 30 m resolution land cover data to map wetlands and assess wetland change between 1990 and 2014 in Gauteng. Both the 1990 and 2014 land cover data have 72 identical land cover classes, which make them comparable. Noting however that while the resolution of these datasets is coarse for this type of analysis, it is the highest resolution data available showing land cover in 1990. In addition to this, the 1990 land cover data, unlike the 2014 land cover data, has not undergone any accuracy testing due to the lack of sufficient reference data. To assess the variation in the outcome of the change detection, this analysis was conducted three times comparing the following data: GTI (2015a) 30 m 2013–2014 land cover data with GTI (2014b) 30 m 1990 land cover data (72 classes), GTI (2015b) 30 m 2013–2014 land cover data with GTI (2015c) 30 m 1990 land cover data (35 classes) and GTI (2014a) 2.5 m 2014 land cover with GTI (2014b) 30 m 1990 land cover data (72 classes); and the findings were very similar. Bearing these above-mentioned limitations in mind, Map 2.6 and Map 2.7 visually compare wetlands in the GTI (2014b) 1990 and GTI (2015a) 2013–2014 (hereafter 2014) land cover data. The analysis in this section, with particular reference to Table 2.1,[4] has been conducted comparing the 1990 and 2014 data mapped in Maps 2.6 and 2.7. In order to ascertain change in wetlands, image differencing has been applied to the two datasets. The extent of wetlands in 1990 has been subtracted from the extent of land cover in 2014 so as to show which land uses wetlands are being transformed into.

Map 2.6 shows wetlands across Gauteng in 1990 and 2014 as separate maps. Wetlands in 1990 are represented in yellow, and wetlands in 2014 are show in green on the maps. An analysis of the distribution of wetlands in 1990 and 2014 shows that wetlands are unevenly distributed across the province and primarily linked with natural water networks. On both maps, the bulk of wetlands are located in Ekurhuleni, which has a relatively flat topography, facilitating the development of wetlands. An overlay of the 1990 and 2014 wetland data on Map 2.7 shows that some of the wetlands observed in the 1990 (in yellow) are no longer present. This is indicated by the lack of green wetlands (indicating wetlands in 2014) in areas previously characterised by yellow in Map 2.6. The loss of wetlands is especially evident in the southwestern part of the province around Khutsong and Carletonville, while other significant losses can be seen in areas around Sedibeng, north of Hammanskraal, Germiston, Grootvaly, Soshanguve and Sebokeng. While there has been wetland loss throughout the province, some wetlands have not changed. Map 2.7 also shows that wetlands have remained intact in some parts of the province; this is indicated by the presence of green wetlands in parts of the province characterised by yellow wetlands in Map 2.6. On the other hand, there has been an emergence of new wetlands in parts of the province, indicated by the presence of green wetlands on the map in areas not previously indicated in yellow in Map 2.6.

The increase in wetlands can be attributed to a range of factors, including recent attempts made by local authorities to conserve and enhance wetlands, the construction of artificial wetlands as well as the seasonal appearance[5] of wetlands in some areas.

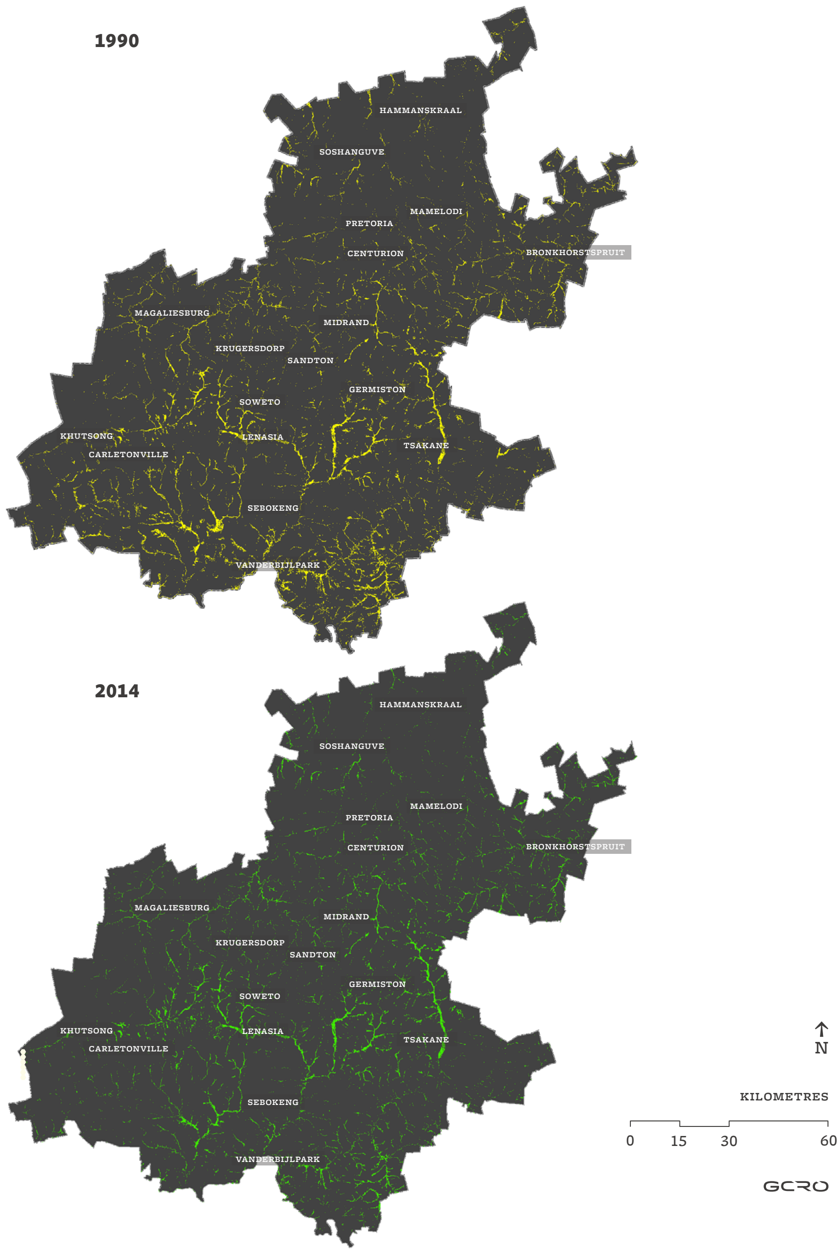
*Wetlands are crucial for the functioning of broader ecological processes as they provide a range of critical ecosystem services to biodiversity, hydrological systems as well as human well-being*

4 The land cover data used in this analysis consists of 72 classes which have been collapsed for further analysis. The collapsed land cover classes used to process the original dataset for comparison in Table 2.1 were shared with the author by Gillian Maree based on previous work and experience.

5 The 1990 land cover data were created using Landsat 4 and 5 imagery, acquired between April 1989 and December 1991. The 2014 land cover data were created using Landsat 8 data, acquired between April 2013 and March 2014. All the data were acquired from the Department of Environmental Affairs Environmental GIS (e-gis) website.

**Map 2.6:** Wetlands across Gauteng in 1990 (top) and 2014 (bottom)

**DATA SOURCES:** MDB (2011a) Gauteng Province boundary; GTI (2015a) 30 m 2013–2014 Land Cover; GTI (2014b) 30 m 1990 Land Cover




Wetlands (as at 1990) | Wetlands (as at 2014) | Gauteng

**Map 2.7:** Wetland change in Gauteng between 1990 and 2014

**DATA SOURCES:** MDB (2011a) Gauteng Province boundary; GTI (2015a) 30 m 2013–2014 Land Cover; GTI (2014b) 30 m 1990 Land Cover


Wetlands (as at 1990) | Wetlands (as at 2014) | Gauteng

Although Map 2.6 and Map 2.7 show some wetland gains in some parts of Gauteng, the change detection analysis suggests an overall loss in wetlands across the province over the period. Gauteng's wetland area has decreased from 631 $km^2$ in 1990 to 535 $km^2$ in 2014. These findings indicate a loss of 96 $km^2$ of wetlands in Gauteng since 1990. However, it is important to note here that the change detection analysis shows that only 309 $km^2$ (49%) of wetlands remained unchanged between 1990 and 2014. The remaining 322 $km^2$ of wetlands that were present in 1990 have been converted to other land uses. There are 226 $km^2$ of wetlands in the 2014 dataset that were not observed in 1990. This may be due to the development of new wetlands across the province, or shifts in the spatial extent of existing wetlands. It is worth noting that very few wetlands have been actively developed by municipalities during this period and this reading may also be due to classification errors or the season in which the satellite imagery was taken (see footnote 5 for image acquisition dates).

It is imperative to identify the main land uses that wetlands are being converted into if efforts are going to be positioned towards minimising further loss and effectively managing wetland ecosystems in the future. Table 2.1 shows that 79% of wetland loss in Gauteng is attributable to the conversion of wetlands to other natural land uses (such as grasslands, low shrubland, thicket, bushland, etc.). This is closely followed by the conversion of wetlands into cultivated land (14%), residential areas (2%) and the drainage of wetlands for fresh water supply (2%). Less than 1% of the wetland loss is attributed to the conversion of wetlands into one of the following possible land uses: mining grounds, degraded and eroded land, commercial space, industries, informal land uses, small holdings, school grounds, and urban sport and recreational areas. However, together these make up 3% of wetland loss.

The finding that the majority of wetland loss across the province is due to transformation into other natural land uses corresponds with the conclusions from other studies looking at wetland acreage and loss (Hu et al., 2017; Millennium Ecosystem Assessment, 2005; Song et al., 2012; Young & Dahl, 1995). The conversion of wetlands into terrestrial land uses may be indicative of the improper use of wetland ecosystems – such as overgrazing or cutting wetland grass and reeds by local community members to make straw mats – sometimes compounding shrinkage due to climatic variations (Wu et al., 2000; Zhang et al., 2011). Wetland change is also indirectly influenced by a number of factors, such as increased levels of nutrients from pesticides, fertilisers and animal faeces leaching into wetlands, resulting in increased aquatic plant growth and algal blooms (National Research Council, 1994).

Some 14% of wetland transformation is due to the use of wetlands for cultivation and agricultural purposes. Agricultural practices often include the damming up of wetland water and its extraction for irrigation, causing wetlands to dry up over time. Farming practices may also result in the salinisation, sedimentation, pollution and eutrophication of wetlands from pesticide use (Galbraith et al., 2005).

While a relatively small proportion (2%) of converted wetlands in Gauteng is subsequently used for the development of residential areas, it remains a serious problem. It is also likely to increase in the near future to accommodate the growing population with adequate access to basic services, noting that Gauteng is already facing a shortage of prime land. The transformation of wetlands into land for urban development requires the drainage of wetlands to make the ground suitable for development.

Examples of such developments include the Inanda Polo Gate, a luxury development by Century Property Developments, which was recently fined R700 000 after building a wall on a section of wetland (Kings, 2018); and Rietvlei Zoo Farm, where the property owner leasing this municipal-owned asset has allegedly facilitated illegal developments on the wetland portion of the site, and is currently involved in a legal battle with the Gauteng Department of Agriculture and Rural Development and the CoJ (Maule, 2018). The loss of wetland systems to residential development deprives existing communities of their ecosystem services, but also places the new residents at risk. Some of the areas across the province showing wetlands loss due to residential development – such as Soweto, along the Klipriver catchment and Germiston – are relatively flat and will (by virtue of having previously been wetlands) have less porous soil types, and thus will be much more likely to be affected by flooding during heavy rainfall events.

**Table 2.1:** The range of land use types that wetlands in Gauteng were transformed into between 1990 and 2014. The rows highlighted in grey are land uses that have observed the highest percentage change.

**DATA SOURCES:** GTI (2015a) 30 m 2013–2014 Land Cover; GTI (2014b) 30 m 1990 Land Cover

| Land use transformation | | 1990 Wetland area ($km^2$) | 2014 Area previously wetlands ($km^2$) | 1990–2014 Percentage wetland loss (%) |
|---|---|---|---|---|
| From 1990 | To 2014 | | | |
| Wetlands | Water supply | 631 | 5 | 2 |
| Wetlands | Natural | | 253 | 79 |
| Wetlands | Cultivated | | 46 | 14 |
| Wetlands | Plantation | | 3 | 1 |
| Wetlands | Mining | | 1 | 0 |
| Wetlands | Erosion | | 0 | 0 |
| Wetlands | Degraded | | 1 | 0 |
| Wetlands | Urban commercial | | 0 | 0 |
| Wetlands | Urban industrial | | 0 | 0 |
| Wetlands | Urban informal | | 2 | 1 |
| Wetlands | Urban residential | | 6 | 2 |
| Wetlands | Schools | | 0 | 0 |
| Wetlands | Urban smallholdings | | 1 | 0 |
| Wetlands | Urban sport and open spaces | | 2 | 1 |
| **Totals:** | | **631** | **322** | **100** |

The findings of this section speak to the need for urgent attention to be paid to the effective protection and management of threatened wetland systems in Gauteng. While this is a very high-level change detection analysis, the mapping provides necessary insight into where associated ecosystem services might have been lost, and where future intervention and rehabilitation of wetlands may be required.

Map 2.6 and Map 2.7 demonstrate that wetlands are not distributed equally across the province and that there has been a further change in the distribution of wetlands over time, with wetland losses and gains in certain areas. Moreover, the maps in this section speak to the main land use types that wetlands are being transformed into, which again affect different areas across the province unequally. Although there has been loss of wetlands in the 25 years from 1990 to 2014, Map 2.6 and Map 2.7 show that there are nonetheless still healthy and functioning wetlands in the province that provide critical ecosystem services supporting both human and natural systems. These are in need of protection and adequate management. The potential consequences of not intervening include, inter alia, increased flooding impacts, deteriorating water quality and biodiversity loss.

## Discussion

The mapping in this chapter looks at three different aspects of GI: the distribution of green vegetation; the proximity of, and access to, green public space; and the degradation of a particular kind of green asset, namely wetlands. Throughout the chapter there is a recurrent theme of inequality. While the uneven distribution of environmental features is certainly due in part to natural occurrences, inequity is largely attributable to human action or inaction, either because of land transformation, planning injustices or poor ecological management and preservation.

Map 2.1 is indicative of green vegetation distribution and serves as a proxy for the quality of the local environment. The low green vegetation readings across the Witwatersrand mining belt, as well as other areas of mine or similar waste, are a mark of environmental damage as a consequence of mining activity. The map also shows that there is an unequal distribution of vegetation – providing key ecosystem services such as temperature modulation and stormwater attenuation – across different residential areas. The highest concentrations are in previously whites-only, wealthy neighbourhoods; the lowest in poorer areas that therefore often suffer multiple disadvantages of high poverty, hard infrastructure backlogs and a lower quality natural environment.

Map 2.2, Map 2.3, Map 2.4 and Map 2.5 consider inequality based on urban planning legacies which have resulted in unequal access to parks and green space across different communities. They indicate where parks and similar recreational space investment have been focused in the past, and where they should be focused in the present.

Similarly, Map 2.6 and Map 2.7 also investigate inequity, although through an alternative lens, showing the inequitable distribution of wetlands across the province and their general deterioration over time. These maps show that there have been changes in wetland ecosystem distribution, in the form of wetland loss or gain, at varying levels across the province. Table 2.1 shows that nearly half of the wetlands observed in 1990 have been transformed to other land uses in the 25 years under review, from 1990 to 2014. Of the transformed wetlands, the majority have been changed or degraded into other natural land uses which might nonetheless provide ecosystem services, but which are likely inferior to wetland ecosystems.

The findings represented in the maps and table raise various questions regarding existing development policies, notably whether these purposefully favour other land uses such as agriculture and housing development, and whether measures in place for the management and protection of wetland ecosystems are sufficient.

Photograph by Clive Hassall

## Conclusion

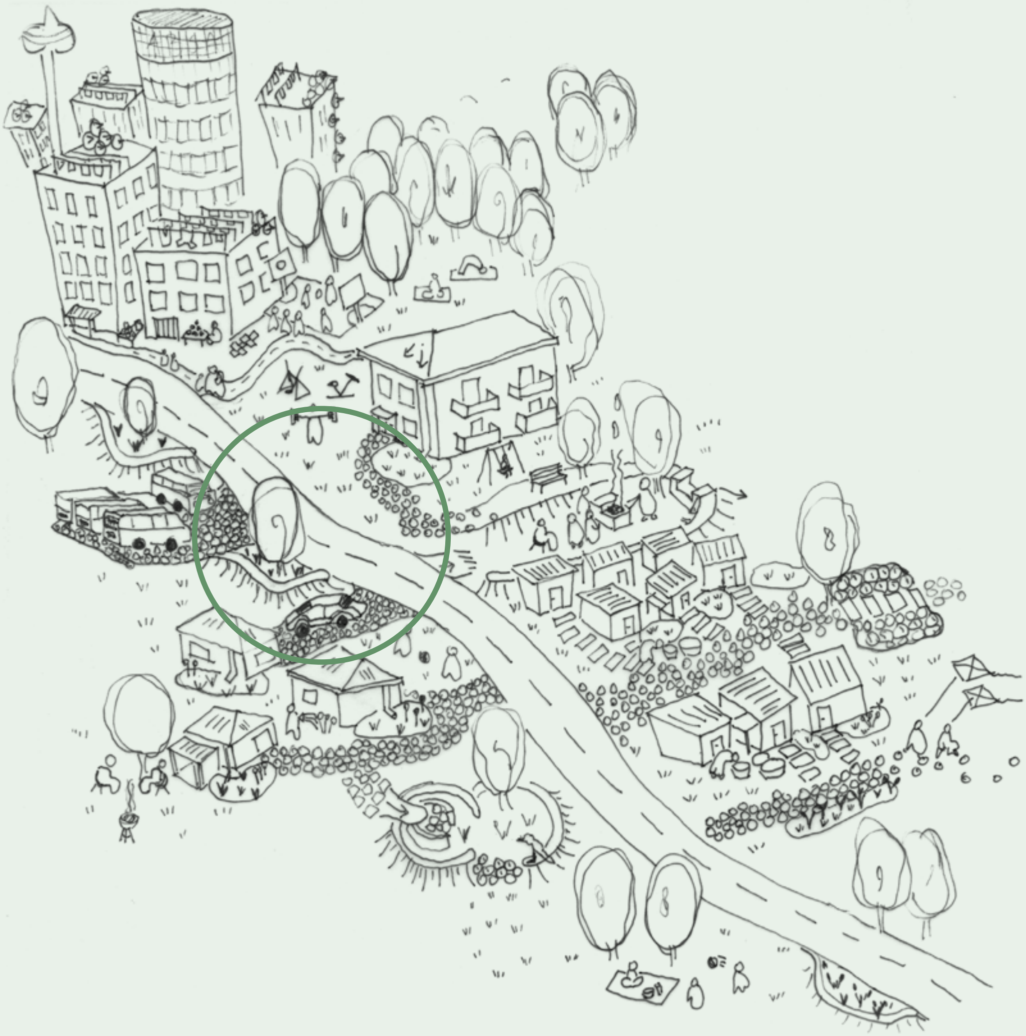
An important component of post-apartheid urban planning has been achieving greater geographic equity in the provision of basic infrastructure. However, Gauteng is characterised by high population growth and, associated with this, increasing consumption of land, which has significant implications for the natural environment and the resources required to sustain it. Adopting a GI approach in urban planning practices could serve to alleviate some of the negative implications accompanying rapid development characterising this region. Moreover, the inclusion of a GI approach in urban planning and infrastructure development practices could provide additional ecosystem services to previously underserved communities, especially where some traditional grey infrastructure networks – such as stormwater drainage channels – are unlikely to be constructed any time soon.

The overarching objective of this chapter has been to help build an evidence base to guide the uptake of GI in urban development efforts by providing better visual representations of the inequity of GI across the province.

This chapter has expanded on the GCRO Green Assets and Infrastructure project's previous efforts to map GI in Gauteng. The mapping has combined spatial data of varying formats and scales in order to derive a comparable picture across different municipal areas. Using alternative data sources, data analysis methods and visualisation techniques, the maps have identified areas of historical green space investment as well as areas that have been historically underserved and are in need of GI investment.

The maps also provide insight into current spatial planning standards and measures, thereby raising questions around the data available to inform the proper management, maintenance and conservation of critical ecosystems.

While the mapping conducted in this chapter is unavoidably at an overview level, it provides key insights that help build a case for a GI approach in Gauteng's urban planning and infrastructure development practice. In future, additional mapping could be done integrating data on socio-economic and demographic trends, and using other innovative methods, to analyse the complex characteristics of GI in Gauteng.



permeable paving

# Chapter 3
# Sustainable urban drainage systems for informal settlements

*ANNE FITCHETT, LERATO MONAMA AND JENNIFER VAN DEN BUSSCHE*

## Key points

- Sustainable urban drainage systems (SUDS) can be considered a subset of green infrastructure (GI).
- SUDS can reduce the quantity and increase the quality of stormwater to combat the effects of urban development while providing the conditions for a healthy and stable ecosystem and increasing the amenity value of the urban environment.
- SUDS have gained popularity in the development discourse due to their improved ability to manage stormwater in urban environments, where traditional methods of controlling runoff are inadequate.
- The paucity of evidence and guidance around how GI can be adapted for informal settlements is a key barrier to its uptake in Gauteng. This chapter explores how SUDS interventions can be applied in informal settlement contexts.
- SUDS can be classified into vegetated areas, pervious areas and water storage. The most effective systems will generally combine two or more of these in series.
- Vegetated areas include swales, filter strips, bio-retention areas and constructed wetlands. These interventions aid surface water management by increasing the surface roughness and therefore reducing the peak discharge, velocity and volume of runoff.
- Pervious areas reduce stormwater volume by temporarily storing water and allowing infiltration into the ground through interventions such as permeable paving and soakaways. These SUDS options provide versatile multi-functional spaces, especially suited to high density settlements.
- Water storage systems help to reduce flood peaks by storing water either temporarily or long term through attenuation or infiltration. Examples of these systems include detention and infiltration basins, retention ponds and rainwater harvesting systems.
- Despite the significant potential for SUDS to help address inadequate stormwater infrastructure, some characteristics of informal settlements (e.g. space limitations and inadequate solid waste management) can undermine the potential for, and viability of, these interventions.

## Introduction

Standard engineering approaches to urban drainage are no longer considered to be best practice because these methods are unable to restore natural flows (Charlesworth et al., 2003; Ellis, 2013). A movement to sustainable options in urban drainage is underway. Sustainable urban drainage systems (SUDS) are best defined as approaches aimed at imitating natural water management processes which have been wholly or partially eliminated due to the influence of urbanisation (Graham et al., 2012).

SUDS can be considered a subset of green infrastructure (GI), which includes green roofs, rain gardens, infiltration planters, tree/pit boxes, vegetated swales, pocket wetlands, buffer filter strips, vegetated open space, riparian river corridors and urban woodland (Ellis, 2013). Ellis (2013) highlights the effectiveness of combining these approaches with infiltration systems such as porous paving and rainwater harvesting. These SUDS approaches are flexible as they can be implemented at plot, site, neighbourhood and catchment scales.

These positive aspects highlight the holistic applicability of SUDS and why some countries have incorporated sustainable drainage into forms of environmental legislation, including the Flood and Water Management Act of England and Wales, and the Flood Risk Management and Water Environment and Water Services Acts of Scotland.

A shift in thinking is taking place to embed these types of GI into spatial planning and consider them as part of the urban infrastructure network (Grant, 2010). However, there has been limited work done in applying GI approaches in informal settlement contexts, where infrastructure intervention is most needed.

Informal settlements are typically characterised by limited, if any, formal infrastructure. Although government in Gauteng has prioritised infrastructure provision for people living in informal settlements, traditional stormwater networks are often very expensive and considered less of a priority than basic services such as water, electricity and sanitation. Engagements with local government and provincial government in Gauteng have highlighted the potential for GI interventions to address surface water and stormwater issues in informal settlements, while improving quality of life for informal settlement dwellers (Culwick et al., 2016). However, the paucity of evidence and guidance around how GI can be adapted for informal settlements is a key barrier to its uptake in Gauteng.

The aim of this chapter is to explore how GI, and SUDS interventions in particular, can be applied in informal settlement contexts. The chapter draws significantly on practical experience in Diepsloot, Johannesburg, and translates traditional SUDS principles and approaches for application in informal settlements. While this chapter is primarily theoretical, the case study detailed in Chapter 4 practically applies some of these proposed interventions in Diepsloot.

The chapter first establishes the overarching principles that underpin SUDS and then goes into detail regarding how traditional SUDS interventions could be applicable in informal settlements.

These interventions are categorised into three groups, including vegetated areas, pervious areas and water storage.

Photograph by Anne Fitchett and Jennifer van den Bussche

## SUDS principles and a GI approach

The adaptability and flexibility of SUDS, as well as the effectiveness of integrating a series of SUDS solutions to form hybrid systems, allows for highly contextualised, extremely unique solutions which can be incorporated into any environment. The literature agrees that SUDS projects should be incremental, following adaptive management practices to optimise performance (Ellis et al., 2012; Woods-Ballard et al., 2007). SUDS are, by their nature, open-ended systems that cascade from one element to the next, thereby avoiding the failures of conventional systems under extreme weather events or when the system has been damaged or compromised, such as when inlets have been clogged by litter.

The use of SUDS can be categorised into three coexisting objectives: reduce the quantity and increase the quality of stormwater to combat the effects of urban development while also providing the conditions for a healthy and stable ecosystem (Charlesworth et al., 2003; Woods-Ballard et al., 2007). In addition, SUDS can increase the amenity value of the urban environment by bringing nature back into the cityscape (Graham et al., 2012).

SUDS have gained popularity in the development discourse due to their improved ability to manage stormwater in urban environments, where traditional methods of controlling runoff are inadequate (Graham et al., 2012; Kirby, 2005). The goal of SUDS is to achieve integrated, holistic catchment-scale solutions through a series of integrated installations that allow excess water to overflow into the next element in a chain of interventions. This is in direct contrast to conventional systems, in which each element of the system is intended to take the entire volume of the water entering the system (Charlesworth et al., 2003; Ellis et al., 2002). Woods-Ballard et al. (2007) explain that SUDS imitate a natural catchment by incrementally reducing the stormwater volume and speed while also increasing the water quality.

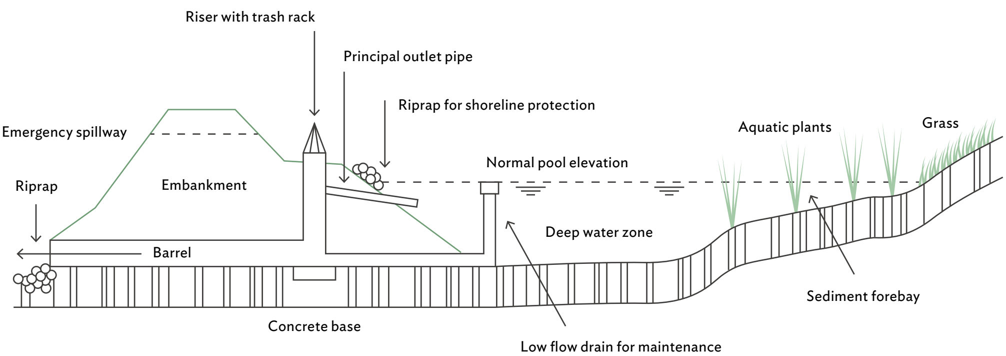
Figure 3.1 demonstrates one possible application of this, showing inflow from the right of the image to the detention pond ('deep water zone') via a sloping area planted with water-tolerant species that assist in erosion control and litter capture. When the water level in the detention pond reaches the top of the 'low flow drain', the water from this higher level flows through the pipes to the outlet on the left. If there is a very high-volume storm of short duration, the detention pond will fill higher than the top of the drain, which will not be able to carry away the excess water quickly enough. The embankment on the left is designed to take this overflow, and is at a height such that the high level of the detention pond does not backwash to the right of the image, potentially causing flooding. The series of SUDS in this type of intervention do not rely on one component to manage the runoff, but rather reduce the risks of flooding by acting in union.

The process of filling the detention pond and overflowing takes much longer than the storm duration, so the flow is attenuated and the peak flow is reduced in comparison with water being channelled in the conventional way, thereby reducing stress on the conventional infrastructure and on the receiving body of water (Jones & Macdonald, 2007; Parkinson et al., 2007). Water flowing over impervious surfaces directly into a conventional stormwater system creates a first 'peak' in the volume being carried, whereas the water flowing through various SUDS will reach the conventional system after this initial peak has passed (Charlesworth et al., 2003). The time delay also allows for settlement of pollutants and encourages recharge of the underground aquifer, especially if some, or all, of the SUDS elements are permeable (Ellis et al., 2012).

*SUDS have gained popularity due to their ability to manage stormwater in urban environments*

**Figure 3.1:** Constructed wetland

**SOURCE:** Clemson University Extension (n.d.)




The time lag further protects the receiving body of water in that the temperature of the water can be reduced to ambient levels, preventing the heat stress that is usually experienced by urban water bodies from the rainwater being heated when passing over dense materials such as concrete and dark surfaces such as tarmac (Charlesworth et al., 2003). This warmed water tends to retain much of its heat through a conventional stormwater system, discharging finally into a natural watercourse as sudden spout of warmer water. The abrupt change in temperature has been found to harm certain riverine species (Jones & Macdonald, 2007). SUDS can loosely be classified into three types (after Charlesworth et al., 2003): vegetated areas; pervious areas; and water storage. As has been discussed previously, the most effective systems will generally combine two or more of these in series, each element serving to address a part of the stormwater (or surface water) volume and each helping to improve the water quality and aquifer recharge.

A selection of each of these SUDS categories is discussed in the following sections. The selected SUDS options have been chosen for their applicability in informal settlements with regard to space availability, cost, robustness, mutability of the urban layout, and fragility of most of the private dwellings. There is a wealth of literature on more conventional systems and elements, such as green roofs and retention ponds, but their applicability would tend to be restricted to a handful of public and more formal buildings, such as schools.

*The most effective systems will generally combine two or more of the SUDS interventions in series*

## Vegetated areas

Vegetated areas that can be classified as SUDS include swales, filter strips, bio-retention areas and constructed wetlands (Charlesworth et al., 2003). Vegetated areas are adapted to take up a greater volume of surface water than a similar land area in a natural environment. This is achieved by directing surface water from the surroundings into the system and shaping it to slow down or store water for various durations.

Vegetated SUDS aid surface water management by increasing the surface roughness and therefore reducing the peak discharge, velocity and volume of runoff. Figure 3.4 provides an example of how vegetation can be introduced for surface water management. The reduced velocities allow for the sedimentation of pollutants while the vegetative nutrient uptake further purifies the water (Ellis et al., 2012; Woods-Ballard et al., 2007). The runoff can be designed to infiltrate into the underlying soil, which mimics the natural hydrological cycle and aids in groundwater recharge (Parkinson et al., 2007; Woods-Ballard et al., 2007). The vegetation provides a number of other environmental advantages beyond surface water management, such as evapotranspiration (evaporation from plants and soils), shade, absorption of carbon dioxide and other pollutants, and the enhancement of urban amenity.

It should be noted that while vegetated SUDS offer a multitude of advantages, regular maintenance is needed to remove litter and fatty-acid build-up where high levels of domestic wastewater are produced (Parkinson et al., 2007). The type of plants should be chosen with care and it is advisable to first assess the expected volume of runoff. Ideally, one or more of the residents in an area with a vegetated SUDS installation should be encouraged to serve as custodian to ensure regular attention. It should also be noted that the installation should be tested regularly for water and soil pollutants if it is used for urban agriculture, as contaminants can be absorbed into the food.

Photograph by Anne Fitchett and Jennifer van den Bussche

## Swales

### 1. What are they?

Swales (Figure 3.2) are linear, vegetated drainage features that are designed to store or transport surface water at lower velocity (Woods-Ballard et al., 2007). They can be designed to reduce the volume of runoff by incorporating infiltration, which in turn encourages slow, uniform flows to allow the pollution to settle out of the water (Woods-Ballard et al., 2007). Swales are typically implemented between or adjacent to road lanes (Figure 3.3), using discontinuous kerbing to permit flow along the length of the swale (Wilson et al., 2015).

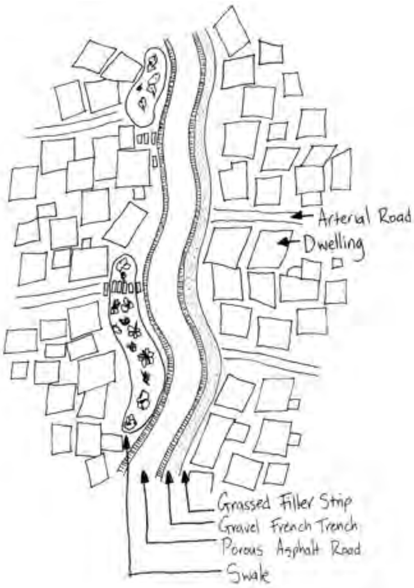
**Figure 3.2:** A swale introduced in between a road surface and concrete pedestrian lane

**SOURCE:** Postel (2014)

### 2. How they work

The emergent vegetation reduces the velocity of runoff by increasing the surface roughness (Brooker, 2011), but in areas where there is a steep gradient, the velocity can be further reduced with the introduction of weirs, check-dams or berms (raised banks) along their length (Woods-Ballard et al., 2007). When dealing with permeable soils, infiltration and the volume of water stored can be increased by filling the bottom of the bed with gravel (Woods-Ballard et al., 2007). Where the natural ground is impermeable, such as clay or rock, a perforated pipe can be included in the gravel layer to assist in the transportation of the water, or infiltration can be disregarded to mimic a small-scale wetland (Woods-Ballard et al., 2007).

**Figure 3.3:** Plan view of swale along a road




### 3. Informal settlement application

One additional advantage of swales is that they are relatively easy to maintain because pollution and blockages are visible and easy to access for cleaning (Woods-Ballard et al., 2007). This is especially important in informal settlements where there is a low level of garbage removal service. Swales are flexible in that their size and function can be altered to suit the need of the region they are implemented in, making them useful in areas such as Diepsloot, where the lanes are very constricted.

## Filter strips

### 1. What are they?

A filter strip (Figure 3.4) is a vegetated area specially designed for the separation of sediment, organic material and other pollutants from runoff from upstream development and wastewater (Charlesworth et al., 2003; Woods-Ballard et al., 2007). Filter strips are often placed in between impervious surfaces and receiving streams, rivers and other hydrological features as a tool to partially treat water before entering the water source, and simultaneously they encourage evapotranspiration and infiltration while reducing runoff velocities (Woods-Ballard et al., 2007).

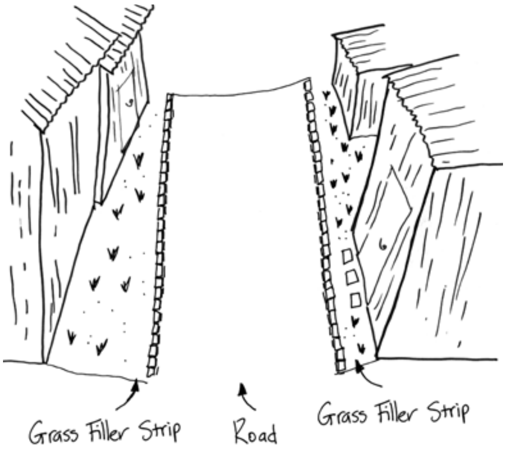
**Figure 3.4:** A simple filter strip adjacent to a road

**SOURCE:** Chesapeake Stormwater Network (n.d.)

### 2. How they work

Cahill et al. (2011) describe filter strips as 'flattened swales'. Sizing of filter strips is site specific; however, Woods-Ballard et al. (2007) recommend that water depths in the filter strip should not exceed 50 mm to allow sufficient water quality treatment and they should also have uniformly graded, mild slopes to reduce incoming runoff velocities (Woods-Ballard et al., 2007). Cahill et al. (2011) add that conventional filter strips should span over the entire impervious surface that feeds into it.

**Figure 3.5:** A proposed grass filter strip applied to an informal settlement




### 3. Informal settlement application

Smaller versions of filter strips work well in high density settlements. Figure 3.5 shows a proposed grass filter strip that may be applied to an informal settlement such as Diepsloot. Furthermore, they are beneficial in treating surface runoff through their filtration properties. Filter strips require mild slopes and they cannot be implemented in areas where there is risk of contaminating the groundwater in reservoirs or natural storage areas below the ground (Woods-Ballard et al., 2007). They are also generally easy and affordable to construct and act as a suitable pre-treatment option (Woods-Ballard et al., 2007).

## Bio-retention areas

### 1. What are they?

Bio-retention areas are shallow depressions within the landscape which can be in the form of a rain garden (Figure 3.6) or a bio-retention filter (Woods-Ballard et al., 2007). A rain garden can be thought of as a sunken flowerbed and a bio-retention filter can be thought of as a small retention pond filled with vegetation (Figure 3.7). They are designed as a temporary water storage unit, where runoff fills into the bio-retention depression and is stored. A portion of the water infiltrates through the soil and is purified through the separation of particulate matter from the sand, as well as the absorption of nutrients by the vegetation (Brooker, 2011).

**Figure 3.6:** Example of rain garden installed in a residential area

**SOURCE:** Garden Drum (2012)

**Figure 3.7:** A bio-retention pond in a public environment

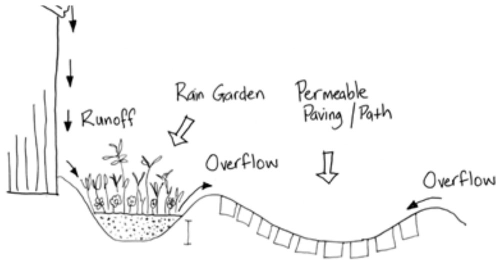
**SOURCE:** *Il faut cultiver notre jardin* (2014)

### 2. How they work

Ideally, bio-retention areas are positioned close to a stormwater point source (e.g. a rainwater downpipe) or surface water. As with swales, when dealing with permeable soils, the bottom of the bio-retention area can be filled with gravel (Figure 3.8) to increase the volume of runoff stored and infiltrated (Woods-Ballard et al., 2007). A perforated pipe can be included at the bottom of the gravel layer if the designer wishes to feed excess water into a river or another type of SUDS.

Brooker (2011) notes that if runoff carries a significant amount of litter and/or sediment, clogging of the system can occur. In addition, the soil type is of critical importance. Bio-retention ponds cannot be constructed in low permeability soils, such as clay, because the soil will resist water percolation (Brooker, 2011), resulting in ponding for long periods of time.

**Figure 3.8:** Rain garden and permeable paving installed in an informal settlement




### 3. Informal settlement application

There are contradictory opinions in the literature regarding the applicability of bio-retention areas in the urban context. Some argue that bio-retention can be applied in urban areas (Parkinson et al., 2007) and even that they are ideally suited for high-density residential housing areas (Graham et al., 2012), while others demonstrate poor suitability of bio-retention for high-density development (Woods-Ballard et al., 2007). Parkinson et al. (2007) contextualise detention ponds to informal settlements by acknowledging that there is little publicly owned land to implement such services. However, these SUDS are a highly flexible approach which can be introduced into the environment at different scales (Brooker, 2011), rendering them applicable at a small scale. They are also suitable directly below roof overhangs where the structure cannot accommodate gutters.

## Constructed wetlands

### 1. What are they?

Constructed wetlands (Figure 3.9 and Figure 3.10) consist of saturated soils with varying shallow water levels and an abundance of vegetation (Woods-Ballard et al., 2007). The moist vegetated land stimulates ecosystems and increases biodiversity, which in turn creates aesthetic appeal and recreational options (Brooker, 2011). Although a wetland's primary purpose surrounds the purification and retention of water, an amount of water will also be attenuated in a flood through the reduced runoff velocity and temporary storage above the design water level (Woods-Ballard et al., 2007). The water is purified through sedimentation in shallow ponds as well as through the pollutant uptake by the vegetation (Brooker, 2011).

**Figure 3.9:** An example of a constructed wetland
**SOURCE:** ArchDaily (2015)

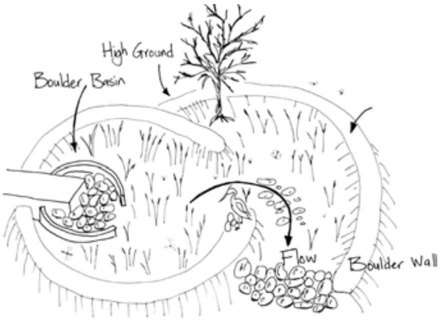
**Figure 3.10:** Constructed wetland near Canberra, Australia
**SOURCE:** Webb (2013)

### 2. How they work

There is a large variation with respect to design, size and water levels of constructed wetlands. Water levels can be low and even hidden from the surface or there can be an abundance of ponds or even channels present (Woods-Ballard et al., 2007). Similarly, this variation exists with size, with options of occupying hectares of space to micro or pocket wetlands (Woods-Ballard et al., 2007). Important suitability criteria for the use of wetlands includes the need for low slopes and sufficiently impermeable soil to ensure constant base flow. It would be beneficial to use wetlands if clay or silt soils are present (Woods-Ballard et al., 2007).

An important factor in constructed wetlands is the use of an inlet to provide initial filtering of sediment and to act as a diversion structure when there are high return periods (Brooker, 2011). In areas of high pollution, litter traps can also be introduced directly at the inlet to prevent clogging in the ponds and amongst the vegetation.

**Figure 3.11:** Possible wetland for the Diepsloot river junction




### 3. Informal settlement application

Although wetlands tend to be difficult and expensive to construct (Woods-Ballard et al., 2007), they are worth exploring in areas such as Diepsloot, which is intersected by the Jukskei River. Figure 3.11 shows how a possible wetland for the Diepsloot river junction could look. The flat floodplains of this river as it passes through Diepsloot provide great potential for wetland approaches, especially in sections that experience illegal dumping.

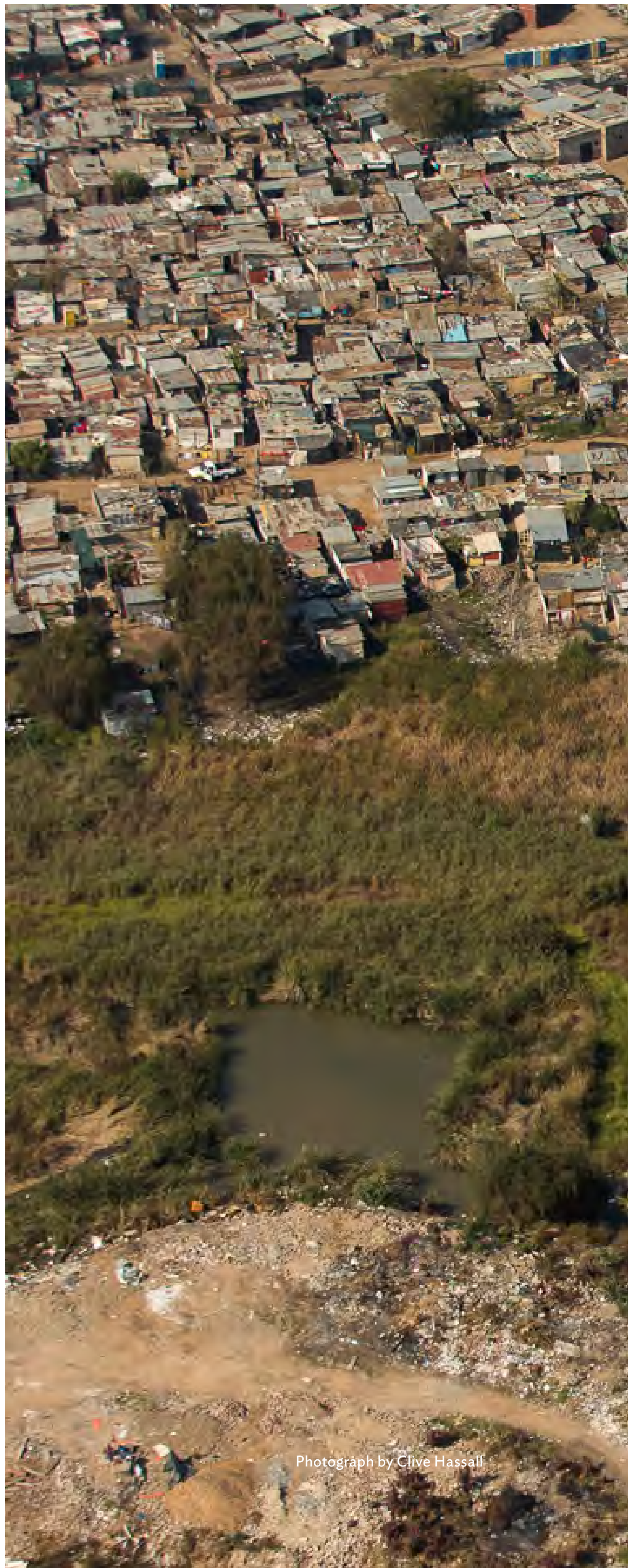

Photograph by Anne Fitchett and Jennifer van den Bussche

## Pervious areas

Areas that experience high traffic (pedestrian or vehicular), where litter cannot be easily managed and where buildings are close together, may not be suited to vegetated SUDS (Jones & Macdonald, 2007). A range of different types of permeable solutions have been developed that create a dual use space, a hard surface and a stormwater runoff system (Woods-Ballard et al., 2007). The discussion that follows considers the use of paving, soakaways and agricultural drains for stormwater management.

The percolation of runoff through the surface of the pervious area helps pollutants to settle out of the water (process of sedimentation) (Ellis et al., 2012). The volume of stormwater is reduced by temporary storage in these systems and by infiltration into the ground (Brooker, 2011). Although these SUDS options provide versatile multi-functional spaces, especially suited to high-density settlements, the ecological and urban amenity benefit is low (Woods-Ballard et al., 2007). Regular inspection and maintenance are needed for pervious areas: the surfaces should be cleared of sediments and litter that block the surface and reduce the infiltration capacity of the area (Jones & Macdonald, 2007).

There are several examples of pervious and semi-pervious paving in Diepsloot (Figure 3.14 and Figure 3.15). One of these provided inspiration for the paving in Godfrey Moloi Street, Diepsloot. This has become more prevalent in the area since initial interventions, which suggests that this intervention is effective in an informal settlement context.



Photograph by Clive Hassall

## Permeable paving

### 1. What are they?

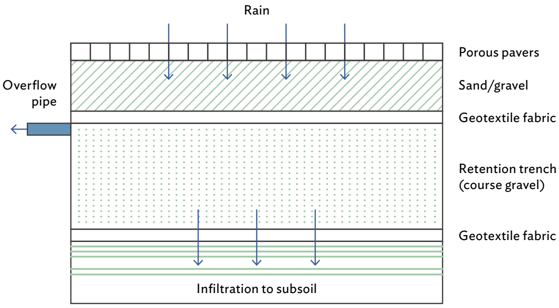
Permeable pavements are SUDS which allow water to infiltrate through the surface into a constructed sub-base layer and/or the underlying ground (Jones & Macdonald, 2007). It is important to consider that permeable paving is most effective when used in a multi-component drainage system (Poleto & Tassi, 2012). Distinction can be made between different types of permeable paving by comparing the path of water once it has filtered through the surface (Woods-Ballard et al., 2007). It is possible to simply allow the infiltrated water to continue into the underlying natural soils, or one could design for an event whereby the natural soil becomes saturated and perforated pipes at the bottom of the sub-base are used to transport the excess water to outlet drainage channels (Jones & Macdonald, 2007). When dealing with impermeable soils or a situation where infiltration is not favourable, due to a risk of soil contamination for example, perforated pipes have to be used to convey the water (Poleto &Tassi, 2012).

### 2. How they work

Permeable paving can be constructed by using porous materials (Figure 3.13), namely porous asphalt paving and porous concrete paving. The gaps between the blocks are then filled with fine sand (Brooker, 2011). The other option (Figure 3.12), is to use hollow interconnecting concrete bricks which can be filled with gravel, or vegetation can be planted in the spaces (Brooker, 2011).

**Figure 3.12:** Hollow bricks
**SOURCE:** Darling Downs Brick Sales (n.d.)

**Figure 3.13:** Detail of permeable paving
**SOURCE:** Adapted from Melbourne Water (n.d.)



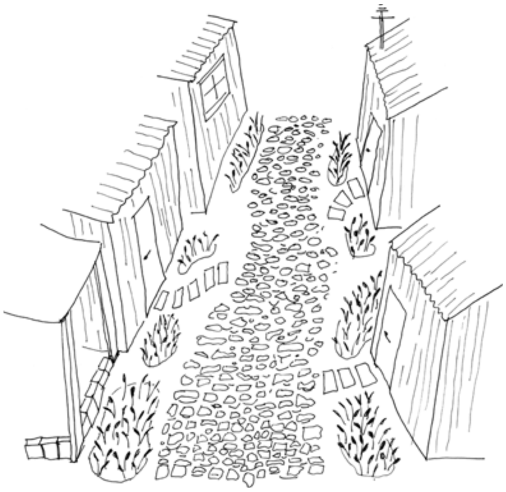
## Permeable paving (con.)

### 3. Informal settlement application

Permeable paving as a tool in sustainable urban drainage is appealing because it is a multi-functional solution, which accommodates stormwater while also being used as paving for pedestrians and cars. In Diepsloot, the unpaved lanes between houses naturally become the waterways for stormwater runoff, which has resulted in severe erosion that traps litter and retains water (Fitchett, 2014). The applicability of permeable paving solutions in Diepsloot is increased by their ability to be implemented in high-density areas and are generally accepted by the community (Woods-Ballard et al., 2007). It is also possible for these paving systems to be constructed over waste or a similar fill as long as the compaction is adequate and does not result in differential settlements (Woods-Ballard et al., 2007). Based on experience in Diepsloot, this has proven to work well in managing domestic surface water, which percolates under the paving, preventing standing water, erosion and the accumulation of litter.

**Figure 3.14:** Brick permeable paving in Diepsloot
**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

**Figure 3.15:** Permeable paving opportunities for alleys in Diepsloot



## Soakaways and agricultural drains

### 1. What are they?

Soakaways (Figure 3.16) are shallow linear excavations filled with gravel, rubble or other materials (Figure 3.18), which create voids (Woods-Ballard et al., 2007). The stormwater runoff infiltrates through the material in these open channels and is then stored in this sub-surface area (Woods-Ballard et al., 2007). The water then infiltrates into the underlying soil. The use of agricultural drains (Figure 3.17) is another common and similar technique; these have perforated pipes at the bottom of the stone media, which transport water to connecting SUDS (Poleto & Tassi, 2012).

### 2. How they work

Soakaways are best used to handle the runoff from a single source (Armitage et al., 2013). Agricultural drains are typically longer and narrower than soakaways, and they can handle larger source areas because the perforated pipe increases the system's capacity (Woods-Ballard et al., 2007). Agricultural drains have traditionally been used in deep foundations and retaining walls to prevent groundwater from penetrating into the building. In these cases, the side of the drain adjacent to the building has an impervious plastic lining. This is a valuable adaptation in closely confined spaces where the agricultural drain needs to run alongside a building.

**Figure 3.16:** Soakaway

**SOURCE:** Woods-Ballard et al. (2007)

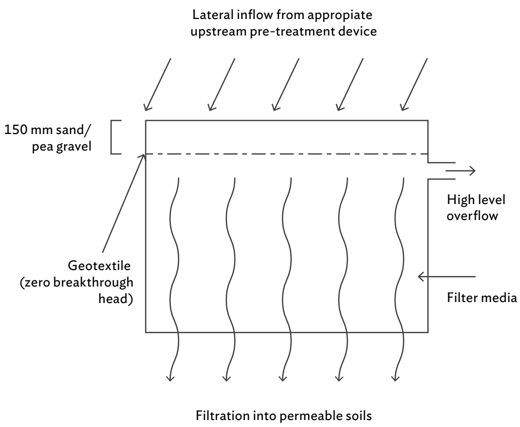
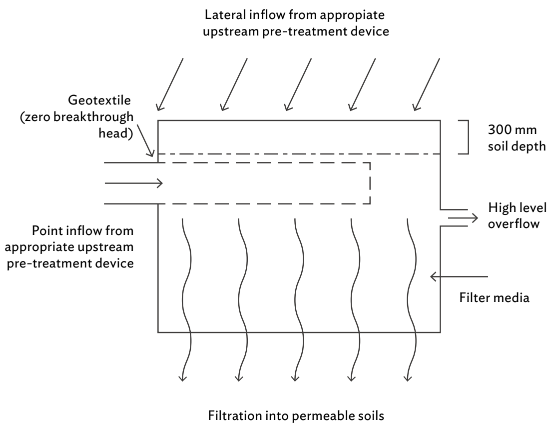



**Figure 3.17:** Agricultural drain

**SOURCE:** Woods-Ballard et al. (2007)

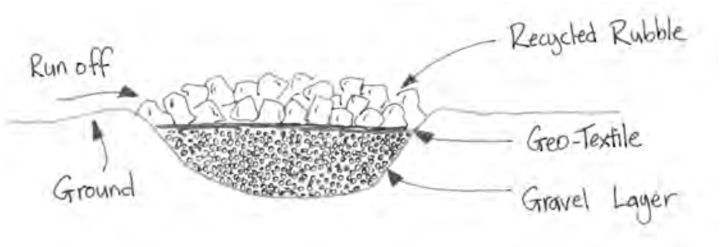



These suds are useful in addressing stormwater runoff by reducing the volume of water through infiltration, improving water quality when filtered through the stone media, and when infiltrating in the soil and recharging underground aquifers (Poleto & Tassi, 2012).

An important design consideration is to avoid the voids in the stone media becoming 'clogged' by sediments. This can be achieved by regular maintenance as well as the inclusion of a pre-treatment system such as a grass strip, which can eliminate large sediments (Woods-Ballard et al., 2007). Armitage et al. (2013) suggest that a geotextile layer can also be considered at the top and bottom of the system to avoid 'clogging', especially if regular maintenance is not feasible. These below-ground interventions can be covered by permeable paving or vegetation, which allow for integration in urban contexts (Woods-Ballard et al., 2007).

## Soakaways and agricultural drains (con.)

**Figure 3.18:** Cross-section of soakaway




### 3. Informal settlement application

The use of these systems in informal settings seems to be fitting. The construction of these systems is economical and they also do not require large amounts of space (Woods-Ballard et al., 2007). Figure 3.19 shows an agricultural drain which was constructed at the end of a micro-swale in Diepsloot. This drainage system prevented waterlogging of the vegetated area directly to the left.

Shallow open channels provide another option in confined spaces (Figure 3.20). They are essentially an adaptation of pervious paving, but shaped and graded to allow the water to flow away from the area with a small amount of percolation. Channels are easy to construct, as they require very little excavation (typically 150 mm to 300 mm deep) and can often take a similar pattern to the spontaneous surface water flow. They can be lined very effectively with half-bricks in a semi-circular form that is inherently robust.

**Figure 3.19:** Constructed agricultural drain in Diepsloot
**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

**Figure 3.20:** Shallow open channel
**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

Source: Morton-Roberts Consulting Engineers (n.d.)

## Water storage

Water storage systems help to reduce flood peaks by storing water either temporarily or long term. This can be achieved through attenuation or infiltration. Attenuation reduces stormwater peaks by storing water temporarily and releasing it slowly. This increases the time taken for water to flow through the system and reduces the volume of the flood peak. Infiltration encourages water to soak into the ground and replenish underground aquifers, thus reducing the total volume of surface runoff.

Attenuation and infiltration both slow down the rate of surface water flow, which helps to control sediment, and the settling and uptake of pollutants. In a water-stressed region such as the Highveld,[1] it is tempting to explore ways of conserving and reusing water from various sources (Enninful, 2013), especially rainwater and domestic 'grey water' from personal laundry washing. However, care needs to be taken of potential contaminants in stored water bodies, including sewage and surface pollutants, which often require these systems to be linked with pre-treatment systems (Woods-Ballard et al., 2007). This section discusses water storage systems, namely, detention and infiltration basins, retention ponds and rainwater harvesting systems.

1 The Highveld region comprises an area in the central plateau of South Africa that is characterised by a temperate climate, dry winters and wet summers with short duration and high intensity storms, and a long dry season.

Photograph by Clive Hassall

## Detention basins

### 1. What are they?

Detention basins follow a similar function to bio-retention areas in that they assist in the attenuation of runoff by creating a storage area for excess water (Parkinson et al., 2007). They are generally larger in size than retention ponds and can be used as a recreational facility when dry or not in use (Woods-Ballard et al., 2007; Graham et al., 2012). Figure 3.21 and Figure 3.22 provide examples of how detention basins can be incorporated into an amphitheatre for multi-functional use. However, unlike retention ponds, they do not reduce the runoff volume but only attenuate it through the temporary storage of the water (Brooker, 2011). Detention basins are also used as temporary sediment control mechanisms where ponding water allows sediment to settle before it is discharged (Woods-Ballard et al., 2007).

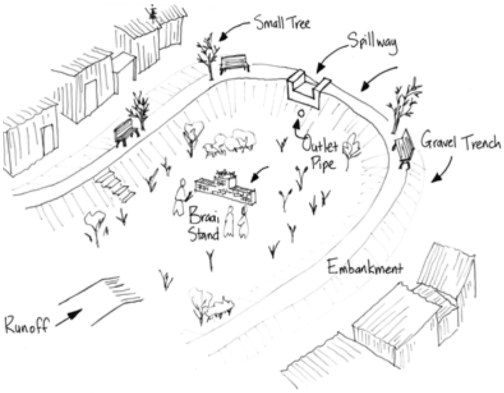
**Figure 3.21:** Amphitheatre incorporating a detention pond

**SOURCE:** World Landscape Architect (2007)

### 2. How they work

Detention basins are typically sized according to the size and frequency of flood that is being planned for (Woods-Ballard et al., 2007), and hence can range from relatively small temporary dams to large expanses holding large volumes of water. Brooker (2011) highlights the four components that detention basins are comprised of: inlets, the storage basin itself, a throttled outlet and an emergency overflow. It is typical to screen the inlets to trap debris. The throttled outlet is designed to attenuate flow while avoiding overflow as a means of managing runoff rate (Woods-Ballard et al., 2007).

**Figure 3.22:** Proposed schematic diagram of a detention pond recreational area for the informal settlement of Diepsloot




### 3. Informal settlement application

Brooker (2011) notes that detention basins follow the municipal stormwater management standards in South Africa because of their sole focus on peak discharge reduction rather than addressing other impacts of urban stormwater runoff. The multiple uses of detention basins, such as soccer fields or parks, makes them an attractive option to improve public land space (Brooker, 2011; Woods-Ballard et al., 2007). The space required for these systems is large and should be carefully considered before implementing in informal settlements. Maintenance of inlets is essential and water quality should be monitored.

There being limited space in Diepsloot, detention basins are more difficult to implement; however, incorporating social facilities can improve their effectiveness in the area. Figure 3.22 shows a schematic representation of how a detention basin in Diepsloot might look and function.

## Infiltration basins

### 1. What are they?

Infiltration basins are defined as vegetated depressions used to store stormwater runoff, allowing it to percolate into the ground over time (Woods-Ballard et al., 2007). Generally, they are simple, circular depressions on permeable land with a grassy covering (Brooker, 2011; Poleto & Tassi, 2012). Infiltration basins assist in stormwater runoff by reducing runoff volumes (Brooker, 2011; Woods-Ballard et al., 2007). Additionally, they remove pollutants from the water as it filters through the soil and replenishes groundwater reservoirs (Woods-Ballard et al., 2007).

**Figure 3.23:** Example of a grassed infiltration basin
**SOURCE:** Morton-Roberts Consulting Engineers (n.d.)

### 2. How they work

Infiltration systems require a permeable soil to be implemented effectively (Brooker, 2011; Woods-Ballard et al., 2007). Woods-Ballard et al. (2007) also note that pre-treatment of the inflowing runoff is required to remove sediment and silt that would otherwise layer across the infiltration basin. Infiltration basins are best suited for less intense rainfall events, where large volumes of water do not need to be attenuated. Hence it is preferred to design these basins so that most of the water is diverted into the basin instead of remaining along the direct flow path of the stormwater. Conventionally, flat areas are used with small embankment walls to retain the runoff (Woods-Ballard et al., 2007). Infiltration basins can either be lined with grassy vegetation (Figure 3.24) or rocks and gravel (Figure 3.23) to suit the environment it is situated in.

**Figure 3.24:** Example of a large grassed infiltration basin
**SOURCE:** Morton-Roberts Consulting Engineers (n.d.)

### 3. Informal settlement application

There being only a few community-based organisations focusing on environmental sustainability, the maintenance of public spaces, such as infiltration basins, becomes difficult to implement. As there is limited public open space in Diepsloot, especially because flat land is ideal for informal dwellings and other social buildings, the uses of detention basins are limited due to their being less versatile than other SUDS.

## Retention ponds

### 1. What are they?

A retention pond is a permanent water body which retains stormwater and improves water quality. A pond detains stormwater runoff in its temporary storage capacity, which reduces the volume of runoff; this runoff then gets replaced by inflow from the next storm event (Woods-Ballard et al., 2007). The water body has little infiltration and hence does not reduce the volume of runoff, but rather just attenuates or stores the water.

The water quality is improved as a result of this retention; the settling of sediments and pollution is carried down to the bottom of the pond (Brooker, 2011; Ellis et al., 2012). Although ponds cannot retain the entire volume of runoff, the initial runoff and thus the initial inflow into the pond contains most of the pollution (Brooker, 2011). A common design retention time is in the order of three days, which can remove up to 95% of the pollutants (Brooker, 2011). The permanent water body has yet another potential use in harvesting the water, which can then be used in water supply after treatment (Brooker, 2011).

### 2. How they work

It is possible to clarify how retention ponds operate by focusing on three main design zones. Brooker (2011) highlights the importance of using an inlet structure for the pond, which can trap debris and aid in energy dissipation. This feeds into the permanent pool, which is the main water storage and treatment zone. Lastly, the pond requires an exit, which controls the discharge rate (Woods-Ballard et al., 2007). These three zones are illustrated in Figure 3.25.

**Figure 3.25:** Example of a retention pond
**SOURCE:** SUDS Wales (n.d.)

### 3. Informal settlement application

Although a reasonable amount of space is required for a pond, there are ecological, aesthetic and recreational benefits produced by retention ponds. A pond is maintenance-intensive, requiring inlet and outlet cleaning, vegetation upkeep and sediment removal (Woods-Ballard et al., 2007).

## Rainwater harvesting

### 1. What are they?

Rainwater harvesting involves capturing stormwater runoff from a roof (Figure 3.27), storing it in a tank (Figure 3.26) and then utilising the runoff as a source of water supply for various purposes (Armitage et al., 2013). The stored water is most commonly used for non-potable needs, such as flushing toilets, washing and watering plants (Armitage et al., 2013). The water can alternatively undergo a treatment process to provide potable water (Brooker, 2011).

The storage of stormwater aids in reducing the peak discharge of a rainfall event considerably (Brooker, 2011) as well as reducing the demand on potentially strained municipal water systems. Non-potable uses of water are commonly met by using highly purified municipal water (Brooker, 2011), but rainwater harvesting introduces an opportunity to meet those needs sustainably.

**Figure 3.26:** A recycled system made from a drum, plastic liner, meshed funnel

**SOURCE:** Enningful (2013)

### 2. How they work

Brooker (2001) highlights four main elements in a rainwater harvesting system, namely, a catchment area, a screened inlet system, a storage tank and a discharge system. The amount of water collected depends on the type and size of the catchment area (often a roof). Potential contamination from the roof should be considered, such as harmful paints (Brooker, 2011; Woods-Ballard et al., 2007). The storage tank can be above or below ground (Woods-Ballard et al., 2007) and the type of reservoir can vary from concrete-lined tanks, Jojo™ tanks to recycled drums (Enninful, 2013). Jojo™ tanks are most applicable in informal settlements as the capital cost and maintenance requirements are lower than for the other options. The distribution system is just as versatile with the choice of different pumps (Woods-Ballard et al., 2007), a simple tap at the bottom of the tank (Brooker, 2011) or it could involve manual removal with a bucket (Enninful, 2013).

**Figure 3.27:** Rainwater tank connected to a communal building drainage outlet

**SOURCE:** Rainharvest (2010)

### 3. Informal settlement application

Rainwater harvesting has been used in South Africa in low-income development programmes, such as Bothlabela Village in Alexandra, Johannesburg, or Indlovu Centre in Khayalitsa, Cape Town (Enninful, 2013). These projects are of particular value as they provide a supplementary water supply to the municipal system, which many of the residents cannot afford. These projects also aimed to increase social welfare by teaching residents the necessary skills to retrofit the systems onto houses (Enninful, 2013). The flexibility of these systems allows them to be installed in single dwellings or in larger buildings such as schools, laundromats or car washes. An example in Diepsloot is the formal taxi rank, in which the roofs over the queueing areas are sloped inwards to shared gutters that discharge into downpipes that lead to nearby storage tanks. It was intended that this water would be available to the taxi drives for washing their vehicles.


Photograph by Clive Hassall

## Conclusion

This chapter has demonstrated how SUDS interventions could be translated for informal settlement contexts in Gauteng and elsewhere. While this chapter has emphasised the significant potential for SUDS as part of a GI network to help address inadequate stormwater infrastructure, some characteristics of informal settlements (e.g. space limitations and inadequate solid waste management) can undermine the potential for, and viability of, SUDS interventions. The pilot case in Diepsloot (detailed in Chapter 4) provides critical insight into how GI can be applied in informal settlements, using the theoretical basis that has been laid out in this chapter.

> *The adaptability and flexibility of SUDS, as well as the effectiveness of integrating a series of SUDS solutions to form hybrid systems, allows for highly contextualised, extremely unique solutions*

Photograph by Clive Hassall

filter strips

## Chapter 4

# Green infrastructure stormwater solutions for Diepsloot, Johannesburg

*ANNE FITCHETT, LERATO MONAMA AND JENNIFER VAN DEN BUSSCHE*

## Key points

- This chapter focuses on informal settlement contexts as key areas of densification within urban areas, where liveability and environmental quality can be significantly improved through introducing sustainable urban drainage systems (SUDS).
- This study uses the principles laid out in Chapter 3 and pilots the use of SUDS interventions within Diepsloot, an informal settlement in the north of Johannesburg. This research tests whether a network of sustainable urban drainage interventions can simultaneously improve the surface water quality while improving the drainage regime.
- Action research and adaptive co-management were used to help evolve adaptable interventions that can respond to the ever-changing physical context of the informal settlement, and nurture self-management of the interventions by the residents of the immediate locality of the two study sites.
- Two sites in Diepsloot were selected for SUDS interventions based on previous experience in the area. Interventions at the first site included a soakaway pit, a semi-pervious drain and permeable paving. The second site included alteration of the eroded gullies to semi-pervious channels and a soakaway.
- Water quality tests were performed by comparing water samples before and after the interventions were implemented to quantify the influence of the SUDS interventions. A range of water quality parameters were considered, including pH levels, conductivity, nutrients and chemical oxygen demand (COD).
- The very simple and inexpensive SUDS implemented in this study not only addressed the removal of the surface water, but improved the water quality at the same time. This is crucial in confirming the applicability of SUDS to the context of informal settlements.
- An important finding of the research lies in the adoption of local practices with regard to recycling. Each of the interventions evolved from experimentation with available waste materials from the immediate area, mostly in the form of construction waste dumped in the informal landfill.
- One practical finding of the research is the interrelationship between surface water and litter in an informal settlement. These each have the potential for undermining interventions of the other.
- Informal settlements, as seen in Diepsloot, are characterised by health and safety crises because of inadequate services and rapidly growing populations. Although the SUDS interventions were small in scale and could not solve the systemic problems in the area, the successes that were evident in this study, including community buy-in and engagement, are significant.

## Introduction

Since the advent of democracy in 1994, the City of Johannesburg (CoJ) has witnessed various types of localised densification, such as cluster housing and office parks, which have supplanted previously low-density residential suburbs. Informal settlements have emerged on open land and existing residential areas have densified with multiple dwellings in the form of backyard dwellings and garden cottages. Both the formal and spontaneous growth have placed increasing strain on the CoJ's stormwater infrastructure.

Densification brings reduction in natural and planted areas and an increase in impervious surfaces, thereby reducing the natural percolation of rainwater and other surface water into the immediate terrain (Archer, 2010; Fatti & Patel, 2013). This surface water, instead of percolating into and replenishing the groundwater, runs into the impervious grey stormwater system and increases negative impacts on the natural water systems that receive the water downstream (Parkinson et al., 2007). For example, roofs of buildings and the surrounding paved areas will have a much greater runoff than the pre-development natural terrain. This increases the volume of water entering the piped, sub-surface drainage system. Negative impacts on the grey stormwater and natural drainage systems into which the water flows include: increased pollution from vehicles and people; localised increase in the volume of water entering the natural system via discharge pipes; and raised temperature of the inflowing water. All of these factors disrupt the functioning of organisms and natural processes, and, in turn, can compromise the viability of natural ecosystems (Lyons et al., 1996) while increasing the chance of flash flooding.

The negative effects of the increase in impervious surfaces associated with densification are particularly extreme in the CoJ because the rainfall predominantly takes the form of intense storms of short duration and large water volume (Fatti & Vogel, 2011). The result of overloading the existing stormwater infrastructure includes damage to infrastructure because the volume and velocity of the stormwater exceeds the system's capacity. This can also cause damage to associated infrastructure (especially roads and other piped services), damage to property through flooding and loss of life (Fatti & Patel, 2013; Fatti & Vogel, 2011). As the CoJ densifies, these problems are expected to occur more frequently in the future (Archer et al., 2010; Harrison et al., 2014).

The potential exists to combine sustainable urban drainage systems (SUDS),[1] a subset of green infrastructure (GI), with the existing grey infrastructure, resulting in 'grey-green infrastructure' (Bobbins & Culwick, 2015; Harrison et al., 2014). The grey-green approach proposes that, with densification, developments should explore stormwater options that do not increase the burden on the existing infrastructure. Such stormwater management options include pervious paving, green roofs, retention and detention ponds, planted swales and rainwater harvesting, all of which have the potential to reduce the overall volume, velocity and peak discharge during a storm. Most of the literature on SUDS is suited to formal sector developments, often requiring additional capital investment, commitment to maintenance and re-planning of open space within the development (Charlesworth et al., 2003; Jones & Macdonald, 2007). By contrast, this study explores the application of SUDS in informal settlements that are characterised by minimal open space and budget constraints because they are often perceived to be temporary by municipal officials and politicians, and who are thus unwilling to commit capital expenditure to large-scale interventions in these areas (Armitage et al., 2009).

1 Sustainable urban drainage systems are designed to mimic natural stormwater regimes by creating pervious elements that facilitate groundwater recharge, reduce the temperature of the runoff and remove pollutants. These often include vegetation to assist with erosion control, increase evapotranspiration and reduce the velocity and volume of the runoff (see Chapter 3).

## The special case of informal settlements

This chapter focuses on informal settlement contexts as key areas of densification within urban areas, where liveability and environmental quality can be significantly improved through introducing SUDS. Informal settlements often spring up on previously undeveloped land (Mafunganyika, 2011; Mupotsa, 2015). In the CoJ, some of these settlements have emerged within the built-up fabric on open land, but are mainly found on the periphery of the City on land that was formerly used for agriculture or pasturage (Harber, 2011). The demand for land in these settlements creates the characteristic form of highly dense single-storey dwellings, with corrugated metal sheeting as a primary building material (Carruthers, 2008; Mafunganyika, 2011). Existing vegetation is almost entirely removed and the small open spaces between the structures are almost invariably of beaten earth. In places, householders use cast-off carpeting or precast panels as a 'paving' solution to prevent soil erosion, especially at the entrances to dwellings (Carruthers, 2008; Mafunganyika, 2011). In this way, the natural surface water regime is almost entirely replaced by impervious surfaces with a high runoff coefficient (Carruthers, 2008).

Lanes between the households tend to take the brunt of the stormwater runoff, becoming open stormwater drains that progressively erode into gullies that trap litter (Figure 4.1) and frequently have standing water held back by the litter (Parkinson et al., 2007). In extreme cases, this makes the lanes almost impassable for pedestrians or vehicles. The situation compounds other issues in the area such as the limited space within dwellings for children to play, and, as a result, it is not uncommon to see children playing around the litter and stagnant water in these lanes.

In many areas, the communal toilets have standpipes and drains attached to the outer wall of the toilet that are often used for clothes washing. When washing water overflows from the small drain, it results in additional runoff. Inadequate maintenance of the standpipes, gullies and toilets in these areas adds to the hygiene and sanitation problems, as well as the degradation of the public domain where social engagements take place (Richards et al., 2007). Despite the lack of basic services, it should be noted that the level of cleanliness and hygiene within the individual households tends to be very high, but the impression to an outsider is of urban degradation, as only the public space is experienced (Mafunganyika, 2011; Richards et al., 2007).

Another feature of informal and semi-formal settlements is that the spatial configuration is highly fluid and transient, with residents constantly adapting their homesteads with additional buildings, replacing temporary buildings with more durable materials, and in areas that are prone to flooding, reconstructing dwellings on raised plinths (Harber, 2011). Frequently, these apparently minor changes in the urban fabric can have unexpected consequences on the surface water regime for the household in question or downstream. Moreover, the rapid rate of erosion undermines properties on higher ground and destabilises embankments of silt lower down in a catchment. Figure 4.2 shows an area where erosion is causing the undermining and collapse of part of a dwelling. A localised surface water solution can therefore become obsolete quite rapidly,[2] or an extreme storm can lead to the collapse of undermined buildings as well as sudden extreme flooding to those directly below the loose embankments (Carruthers, 2008; Parkinson et al., 2007).

2 For example, a resident may construct a pipe or channel to discharge water away from a dwelling into a public area, but the subsequent construction of a neighbour's dwelling could encroach on the discharge, causing the pipe or channel to back up water into the original problem area.

**Figure 4.1:** A typical lane in Diepsloot showing the prevalence of surface water

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

**Figure 4.2:** Erosion causing the undermining and collapse of part of a dwelling

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

## Diepsloot informal settlement

The history of Diepsloot, the case study area for this research, is not rooted in informality but rather in the management plans of the apartheid era (Harber, 2011; Mupotsa, 2015). The district was zoned as a township to regroup informal dwellings in the north of Johannesburg to the then named 'Norweto' (North Western Township) on the CoJ's periphery (Benit, 2002). Areas of the Diepsloot district were provided with services and demarcated sites while a more informal region intended for temporary settlement developed alongside it (Benit, 2002; Mafunganyika, 2011). Included in the formal area of Diepsloot are tarmac roads lined with conventional piped stormwater infrastructure. Since its rapid densification in 1995, the population increased by five times the planned number, with little improvement in infrastructure. Until 1999, Diepsloot was not integrated into the development plans of the CoJ because it was considered 'temporary', which led to a lack of service delivery within the region (Mafunganyika, 2011).

The ever-growing population of Diepsloot puts strain on the inadequate existing infrastructure. Further to this, the inhabitants of Diepsloot have adapted their environment to best suit them, with little planning guidance (Carruthers, 2008; Mafunganyika, 2011). The removal and, consequently, the lack of vegetation, as well as the large amount of impervious surfaces due to rapid densification, have caused a major problem of surface water runoff in the Diepsloot settlement (Adegun, 2013). Earth access lanes, gullies from wastewater runoff and haphazard dumping are prevalent throughout the denser areas of the settlement, which strain the natural ecosystem of the region (Carruthers, 2008). The exposed earth and lack of vegetation create erosion problems and cause further stress to the stormwater infrastructure (Carruthers, 2008). Construction rubble and domestic waste dumping also leach into runoff water, contaminating the pools of stagnant water and the nearby Jukskei River (Carruthers, 2008).

The health risks that arise due to the lack of stormwater infrastructure to manage the volume of water runoff have become a concern within the community of Diepsloot (Carruthers, 2008). Many service delivery protests have occurred in the district around sanitation and the lack of access to potable (drinking) water in the past (Carruthers, 2008). There have been attempts to upgrade the settlement over the years by various municipal management initiatives; however, the plans never correlated with infrastructure development in the region (Todes, 2012). Spatial plans of the time directed the new development of infrastructure, but never attempted to link it with existing infrastructure. Furthermore, the infrastructure departments worked independently on their own agendas (Todes, 2012). Moreover, Todes (2012) highlights that planning was too broad to highlight specific development areas such as sites for schools and clinics.

The COJ's Integrated Development Plan (IDP) has been formulated as a tool to direct development towards sustainability and social equity, and is revised every five years (CoJ, 2013). One of the IDP aims is to rectify the poor standards of living in informal settlements, including Diepsloot (CoJ, 2013). Major improvement plans for Diepsloot include the upgrading of the main road linking the township to the city centre, development of an industrial park within the area, improving bulk water supply and enhancing road networks within the settlement (CoJ, 2013).

Acknowledging its large population and poor living conditions (and perhaps in response to pressure from nearby upper-middle class settlements), the CoJ has listed Diepsloot as a priority development area following the Growth and Development Strategy Joburg 2040 and the Upgrading of Marginalised Areas Programme (Johannesburg Development Agency [JDA], n.d.). In line with this development, the CoJ plans to build 14 000 additional housing units, as well as upgrade the electricity sub-station 'to provide sufficient bulk supply for future development in the area' (JDA, n.d., p. 3). The JDA lists improved mobility, the investment of public amenities and public art as priority interventions (JDA, n.d.). However, this plan does not consider the vital issue of stormwater management in Diepsloot.

Stormwater management is under the jurisdiction of the Johannesburg Roads Agency, which has developed a master plan to address the stormwater management crisis within the informal settlement. The report has determined catchment areas and quantified volumes of precipitation for Diepsloot, resulting in a conventional hydraulic engineering proposal (Civil Concepts, 2010). Nine years have elapsed since the generation of the report, but little has been done to improve the stormwater crisis due to the large costs involved in the master plan, which has led to the questioning of the effectiveness of the proposed approach. The failure of this type of approach can be seen in piecemeal stormwater upgrades throughout the settlement, especially where water runoff from roads has carved gullies between the houses. Moreover, current thinking around the world points to more sustainable strategies that combine the provision of social amenities such as sports fields, playgrounds and visual enhancement of the public domain with vegetated features, while meeting the pragmatic needs of surface water management.

Such initiatives call for a more holistic and incremental approach, one in which community participation plays a fundamental role in that the residents immediately adjacent to each element of the system need to take ownership of it, both to assist in its maintenance and to capitalise on the social amenity.

This chapter uses the principles laid out in Chapter 3 to pilot the use of SUDS interventions within the informal settlement context. This research tests whether a network of sustainable urban drainage interventions could simultaneously improve the surface water quality while improving the drainage regime in Diepsloot. The following sections of this chapter present the research conducted in Diepsloot, including a detailed description of the SUDS interventions that were implemented in two sites in the settlement. This is followed by an analysis of water quality testing, which was conducted before and after the construction of each of the SUDS interventions to quantify their influence on runoff management and quality at the specific sites.

The chapter concludes with a discussion on the outcomes and a reflection on the implementation of SUDS as a component of a GI network in an informal settlement context. The principles of action research and adaptive co-management proved critical in this research. These principles about community participation are detailed in the following section of this chapter.

## Action research and adaptive co-management

Experience from two small pilot projects carried out in 2013 and 2014 indicated the importance of intense participatory engagement with residents of the areas immediately surrounding any intervention. Moreover, literature on SUDS suggests that these interventions should be developed adaptively, with each element of the system being observed and adjusted over time to arrive at an optimal arrangement between all stakeholders. The discussion on some of these elements highlights the need for ongoing maintenance and performance checks, ideally by people living adjacent to them who can monitor litter accumulation and other potentially problematic situations that could cause the system to malfunction.

These factors speak to the desirability of using 'action research', in which the design and implementation of the SUDS in any locality is seen as an incremental process with ideas being shared between residents and 'experts'. This is consistent with South African environmental legislation and policy (e.g. the National Environmental Management Act, No. 107 of 1998) that acknowledge the importance of 'local knowledge systems'.

The following sections provide some context into action research and adaptive co-management, along with how the Diepsloot study was structured to incorporate these principles.

### Action research principles

Action research can be considered to be a 'knowledge partnership' among the various stakeholders, with everyone contributing their views, which are equally respected, and 'owning' the results (Fitchett 2014). Rapoport (1970, p. 499, in Susman & Evered, 1978) defines action research as aiming 'to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework'. The action researcher brings theoretical knowledge as well as breadth of experience to the problem-solving process. The community bring practical knowledge and experience of the situations in which they are trying to solve problems. Neither community nor researcher has better knowledge and, in a sense, they are both experts.

Guidelines from a number of universities that promote action research can be summarised into the steps below (Greenwood & Levin, 2007; Susman & Evered, 1978). Explanation on how these were applied in Diepsloot is also provided:

- Access should be negotiated with all potential role-players and affected parties. This access is both in the physical sense of being able to carry out the research and in the sense of having access to the local knowledge systems.
- When suitable sites have been identified, all of the adults in the affected households should be consulted on the process at all stages, including access to public and private space, their experience of surface water problems and their current strategies to mitigate them, problems that they experience for which they have not developed a solution, and possible interventions.
- The apparent and potential risks of any intervention or other forms of engagement with the project should be shared and discussed with all interested and potentially affected households before proceeding.
- Local civic organisations should be consulted and fully briefed on the project.
- Resident adults should be consulted on their physical involvement, use of their resources (such as tools) and payment for any services provided by them. This should follow a consensus approach driven primarily by the residents.
- All research outputs, including water and soil test results and project reports should be shared with the residents, ideally before dissemination (Susman & Evered, 1978).

In the Diepsloot project, a preliminary survey was carried out with potentially affected households to assess interest and level of engagement. This process was intensified with the two study sites that were finally selected in a series of discussions on the existing stormwater interventions and the potential location of new elements. The South African National

Civic Organisation (SANCO) representative made early contact with the project, but did not follow up with any further interaction. Engagement with residents regarding resources and payment was facilitated by one of the research team who is herself a Diepsloot resident, thereby helping to dissolve the barriers between residents and external researchers and establish the 'knowledge symmetry' promoted in the literature on action research.

## Adaptive co-management

Adaptive co-management is an innovative governance strategy that aims to sustain socio-ecological systems (Plummer, 2009). Ruitenbeek and Cartier (2001, p. 8) define adaptive co-management as a 'long term management structure that permits stakeholders to share management responsibility within a specific system of natural resources, and to learn from their actions'.

This approach exercises the concept of 'learning by doing' where learning is facilitated through feedback. Social and institutional learning is important in adaptive co-management and requires collaboration, joint decision-making and multi-stakeholder arrangements. Kilpatrick et al. (2003, in Armitage et al., 2008) describe how self-organised learning processes allow groups of people with shared interests to proactively address learning through partnerships. Pahl-Wostl (2006, in Cundill, 2010) proposes that learning from adaptive co-management relies on collective action and results in constitutional change in terms of rules, laws, customs and norms. Co-management espouses the idea that rights and responsibilities should be shared among those with a claim to the environment or a natural resource (Plummer, 2009).

In the Diepsloot study, the foundations for adaptive co-management were established through the processes of action research described above. As each of the study sites evolved through the introduction of SUDS, there was much discussion about who should take responsibility for monitoring and maintaining the interventions, possible problems under different storm conditions, and methods to adapt, extend or enhance the interventions. In one of the study sites, possibly because of the strong social cohesion in this area, this process of adaptation continued several months after any direct involvement from the external team members.

Photograph by Clive Hassall

## Introducing SUDS into Diepsloot

This study set out to design and implement SUDS interventions in an informal settlement context. Two sites in Diepsloot were selected for these interventions based on previous experience in the area. The details of these interventions and the respective sites, including criteria for site selection, are foregrounded by initiatives that were previously implemented in Diepsloot. The past experience demonstrates how the community has played an important role in adapting their environment to a more liveable standard. This proved critical in securing buy-in for the two interventions.

### Previous initiatives in Diepsloot 'reception area'

Over the past few years, WASSUP Diepsloot (Water, Amenities, Sanitation Services, Upgrading Programme) has attempted some micro-initiatives to address a few of the problems associated with the degradation of the public realm in the 'reception area' of Diepsloot (Fitchett, 2014). WASSUP's primary mandate is to maintain the communal toilets and standpipes within this part of Diepsloot, funded through a grant from the Development Bank of Southern Africa, administered by the JDA.

The most problematic section of Diepsloot within their remit was King Mpande Street, an important pedestrian link between two tarmac roads. The sewer in this section was constantly blocking surface water flow, exacerbating the surface water problems experienced elsewhere in that the standing water was contaminated with effluent. A preliminary survey in 2013 suggested that it would be pointless to do a SUDS pilot project in King Mpande Street, as this was fed by surface water from higher adjacent streets. The focus therefore moved to Godfrey Moloi Street, a lane that fed into King Mpande.

An intensive participatory process was carried out with the residents of Godfrey Moloi Street to gauge their perceptions and to solicit their ideas for 'street beautification'. Many of the ideas centred on major infrastructural improvements, such as increasing the number of communal toilets, which was beyond the mandate and limited resources of WASSUP. The collective decision was made to pave an area at the highest part of Godfrey Moloi Street, using reclaimed half-bricks that had no resale value. The principle was to create a semi-permeable surface with a soakaway down the centre of the lane, subtly adapting the road contours that had evolved through erosion (Figure 4.3). In this way, the surface water could be managed to prevent stagnant water, yet some of the surface water would percolate into the groundwater and the water flow would be slowed during a storm, reducing erosion and delaying the peak flow into the lower parts of the catchment. Several years later, the paving is still in good condition and serves its purpose relatively well, especially in reducing erosion and in the build-up of litter as the major contributors to standing water. It is interesting to note that paving with half-bricks, from being a rare phenomenon in this part of Diepsloot, has become more prevalent, both for the paving of sidewalks outside businesses and of yards within homesteads. This may be a result of the WASSUP project, or may be a sign of the general upgrading and consolidation associated with informal settlements throughout the world (Abbott, 2002).

The next initiative by WASSUP (in July 2014) was aimed at addressing the surface water that accumulates around the standpipes and gullies adjacent to the communal toilet blocks. This problem is most severe over weekends when householders use the gullies to tip water used for washing clothes. Invariably, water overflows into the immediately surrounding area and flows into the lane, increasing erosion and contributing to the standing water. This water tends to be contaminated with soap, which decomposes into a black sludge that is unsightly and discourages any initiatives to remove street litter. The soapsuds are high in nitrates and phosphates, which can be destructive to natural watercourses as they encourage the proliferation of plant species, thereby reducing the oxygen content of the river and reducing the natural flow. This is of particular significance in Diepsloot because the settlement is intersected by the Jukskei River, the natural receiving water body of the entire Diepsloot catchment.

The concerns expressed by householders in Godfrey Moloi Street focused on the hygiene and safety of the immediate locality. Several of the families have young children who tend to play in the lane next to one of the toilet blocks. The residents' concerns were addressed through a miniature rain garden with graded brick paving around the toilet block and into a small planted area with an agricultural drain to prevent waterlogging. Reclaimed materials with minimal value were used to prevent 'dismantling' and using the materials for other uses.

The rain garden addressed several problems concurrently. It absorbed the standing water from domestic spills at the gullies, reduced litter accumulation and saturation, provided a social space with vegetation and a seating ledge, and reduced the nitrate and phosphate load by their uptake as nutrients for the vegetation.

This initiative has not been as robust as the earlier paving project. The kerbing has not endured foot traffic to the toilets and gullies, with the paving breaking away. This prevents the smooth flow of the surface water into the vegetated area, and has led to the return of the rivulet in the centre of the lane. However, valuable lessons were drawn on exactly how robust these green initiatives need to be.

On the one hand, it is useful for the interventions to be able to be dismantled or reconfigured easily in response to changes in the physical urban layout; yet, on the other, the designs need to acknowledge the extremely high usage that these communal facilities experience to minimise unintended degradation. The poor quality material that was used for the kerb played a large part in the paving degradation, forcing the problem to the perimeter of the intervention. This served as a valuable insight for future work, primarily in appreciating the amount of traffic and wear that the GI needs to withstand, and secondly in ensuring that the resolution of one 'hot-spot' does not simply shift the problem lower down the catchment.

In addition to the WASSUP interventions, there are numerous examples of the spontaneous use of vegetation for rainwater management in Diepsloot, sometimes very evidently intended for this purpose, for example along a section of King Mpande Street, where there is a considerable level change created by a silt embankment. The vegetation helps to retain and stabilise the silt during a rainstorm and the roots absorb more of the water than an unplanted sandbank would. In other examples, there is less evidence of conscious surface water management via planting, but the existing vegetation would inevitably improve localised infiltration.

**Figure 4.3:** Godfrey Moloi Street paving

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

**Figure 4.4:** Vegetation planted for surface water management in Diepsloot

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

In all instances observed, these spontaneous areas of planting are either at surface level or slightly raised, with rubble or brick edging, therefore not fully capitalising on the ability to retain water.

One of the key challenges in informal settlements is in the very limited space within dwellings and in the public domain. The pilot 'micro-projects' undertaken previously in Diepsloot were specifically designed to capitalise on pockets of space that would not encroach on the accessibility ('micro-swale'), or that have enhanced accessibility (pervious paving) by making a more trafficable roadway and levelling up the erosion gully.

The experience in experimenting with micro-interventions in Diepsloot was critical in guiding the design and implementation of the two SUDS intervention sites in this study. These are described in more detail next.

## Criteria for site selection

Figure 4.5 displays a satellite image of the broad study area, which sits on the border of a wetland. After years of illegal landfill dumping, the water is at a higher level than some of the dwellings. This problem worsens downstream towards the west of the settlement.

From an interpersonal perspective, the site area was chosen for a number of reasons. First, a key Diepsloot-based team member and experienced facilitator (Researcher 1) in an area of Diepsloot known as Extension 1 was soon to open a café nearby, therefore monitoring and storing equipment and easy access was a key factor. Second, WASSUP, which the researcher was part of, were having internal disputes. So, the site was chosen as it is not in a WASSUP mandated area.

**Figure 4.5:** Satellite image of the broad study area and specific sites selected for SUDS interventions

**SOURCE:** Diepsloot, 25°93'07.10" S and 28°01'28.07" E, Google Earth (2015)

## Site 1 SUDS intervention

*Location*

Figure 4.6 shows a schematic diagram of the location for Site 1. This site is located at the end of a street on the north side of JB Marks Road, two lanes up from the river crossing. There are six communal toilets on the street, predominantly corrugated iron dwellings, and at the location of the first pilot, there is an outdoor shaded area of a shebeen (tavern) where some of the community sit and socialise, with some gambling and pool playing. Residents had incrementally installed a series of drainage solutions, all leading to a miniature wetland which is lower than all surrounding ground levels, initially full of plants and rubbish.

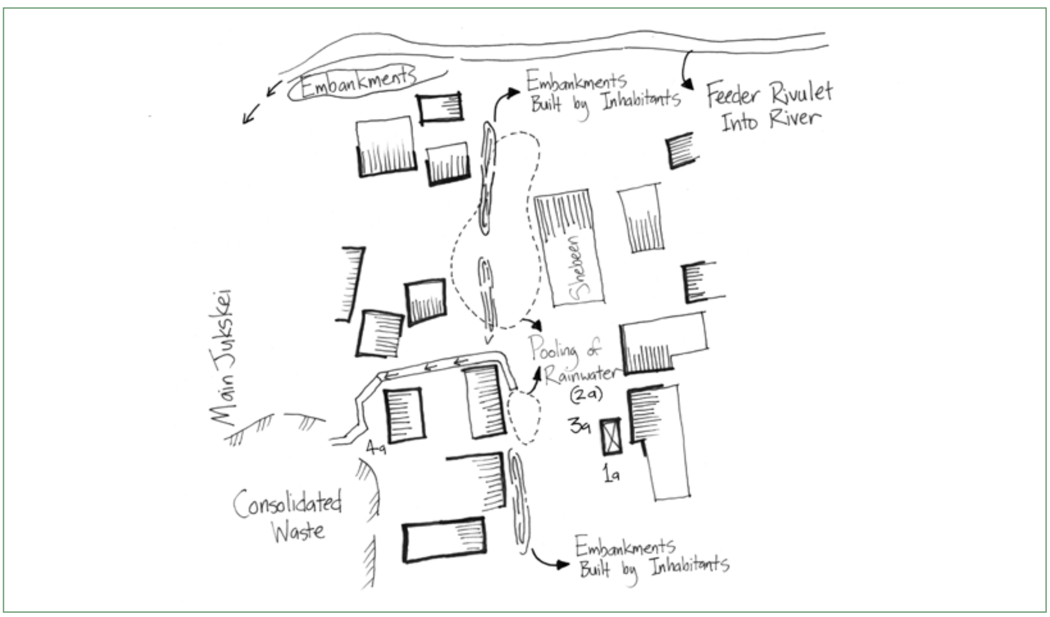
*Visual inspection of Site 1*

At Site 1, it was clear that households had attempted various interventions to manage surface water, including:

- The installation of plastic piping (75–100 mm diameter) to direct the flow of water into a fibreglass box that was buried at a confluence of drains and leading out to the wetland, which has been used as a dumping site;
- Construction of a berm (raised bank) adjacent to a rivulet from the 'Rasta Tavern' to avert flooding, as well as the installation of paving over the forecourt of the tavern;
- In many cases, residents had placed paving and carpets within homesteads, and the surface-beds of dwellings had been raised (250 mm or more) above existing ground level to avoid flooding; and
- Vegetation had been cultivated on homestead perimeters to be slightly raised above ground and level with rockeries in places to prevent erosion.

Residents highlighted the wetland as a source of concern because it is below the level of the surrounding dwellings and the berms shut this area off from the natural watercourse, which increases the potential for flooding. This entire area was also used for dumping (a mix of domestic and construction waste).

**Figure 4.6:** Schematic diagram of Site 1 before any interventions were introduced



*Addressing the community's priority needs*

The residents were asked about the stormwater and drain-related challenges in the area. The response from most residents was the lack of toilets and taps (at the time only one was working, which was used by residents in the entire street). It is evident that there is some open defecation in the landfill site close to this road, and the drains lower down smell of sewage. It is possible that the lack of working toilets contributes to this. Therefore, on the first day of work, it was decided to purchase some parts to repair a communal tap that was constantly running. This action accomplished a few things. It demonstrated that the project team was hands-on and active in solving the community's problems, gaining more community trust, and that the project team acknowledged people's concerns even if we were interested in stormwater, which did not seem to be residents' immediate concern.

**Figure 4.7:** Waterlogging around the toilet block (photograph of point 3a in Figure 4.6)

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

**Figure 4.8:** Blocked snaking pipe before the intervention (photograph of point 4a in Figure 4.6)

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

*Sustainable urban drainage interventions*

First, Researcher 3 and Researcher 1 together with four Diepsloot residents cleared the wetland of surface rubbish. The team used salvaged broken bricks as the primary building material to repair an underground pipe. The pipe had many kinks and was broken at some point, so the team straightened it to allow for rodding and repaired the broken section to prevent blockages in future. A section of the existing piped drain was reconfigured as a shallow open channel, which was then further lined with un-grouted, half-bricks to create a semi-pervious drain that would not block with litter. The existing inspection chamber was turned into a soakaway pit using broken bricks salvaged from the landfill site. Figure 4.9 shows the semi-pervious drain that was created alongside the existing piped drain.

**Figure 4.9:** Installed soakaway pit

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

The soakaway pit was built and covered with a piece of nonwoven, needle-punched geotextile fabric to prevent the soakaway from silting up. The geotextile was removed in the coming weeks to wash out the clogged dirt and silt that collected upon it. However, at some point, the residents removed it altogether and the pit was left uncovered, with broken bricks to cover the top edge. Precast concrete blocks (approximately 300 by 200 by 100 mm) were used to create an edge between the soakaway and the channel. Furthermore, residents suggested that the drain would be improved by filling the joints between the bricks with clean gravel to enhance stability but still allow soakaway.

This highly interactive exercise illustrates the strong sense of confluence of local and academic knowledge throughout the project. Figure 4.10 shows a schematic representation of the above mentioned intervention, Figure 4.11 shows the soakaway pit as it was initially constructed, and Figure 4.12 shows the pit adapted by the residents.

Following the principles of adaptive co-management, a collective decision between the researchers and residents was made to stop work on the site when the team felt that the system would serve the purpose of preventing flooding. The strategy was to wait for a substantial rainstorm to see if it worked before making any further interventions.

**Figure 4.10:** Schematic diagram of Site 1 after the interventions were introduced

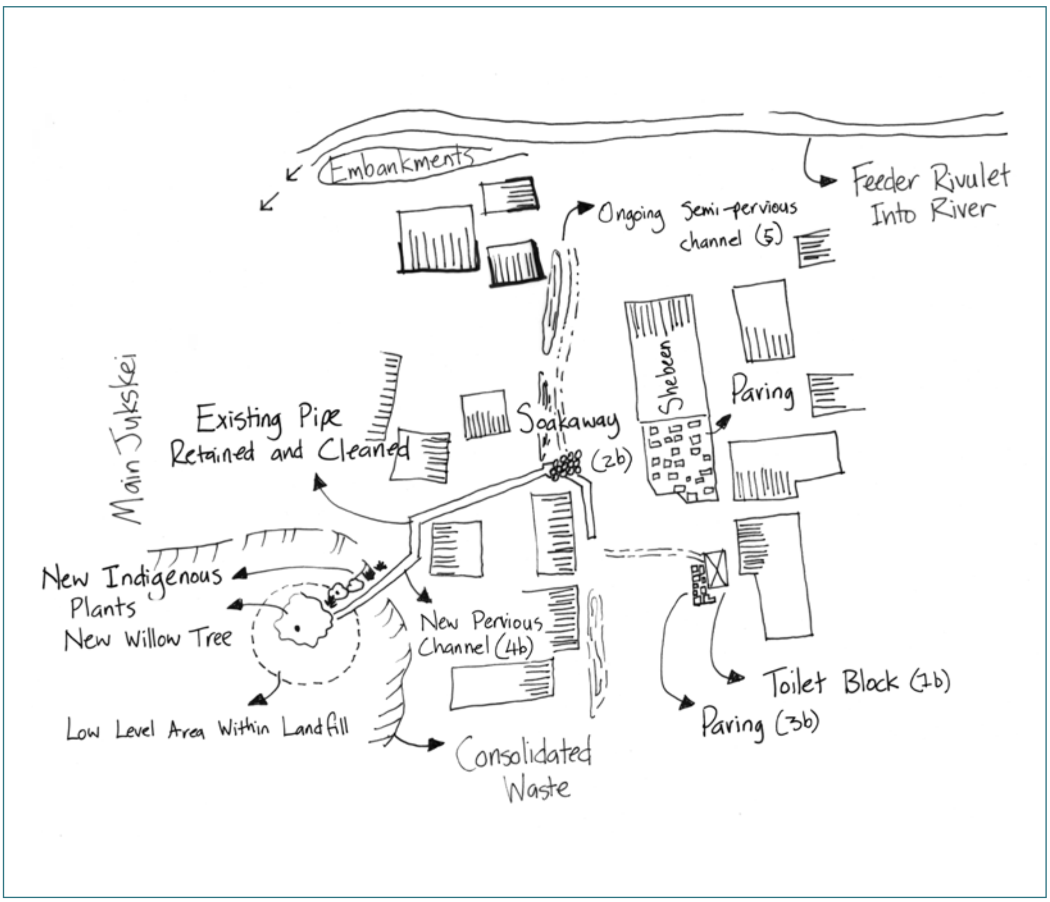


**Figure 4.11:** Pooling surface water at the pipe junction before intervention (photograph at point 2b in Figure 4.10)

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

**Figure 4.12:** Implemented soakaway (photograph of point 2b in Figure 4.10 after implementation)

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

**Figure 4.13:** Graded brick paving around the toilet block with a small agricultural drain to prevent waterlogging (photograph of point 3b in Figure 4.10)

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche


**Figure 4.14:** New pervious paving (photograph of point 4b in Figure 4.10)

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

To ensure the longevity of these interventions, ongoing monitoring and maintenance is required by residents. After a discussion with Researcher 3 about the possible flooding that could occur if rubbish were to collect and block the drain, one of the residents committed to ensuring that the open channel drain would be kept clean. Surrounding households agreed to monitor the new system and give feedback. Although these people committed to maintaining and monitoring an area, this commitment is voluntary and there is a risk that if this commitment wanes, the system could collect rubbish and fail in the event of a flood.

## Site 2 SUDS intervention

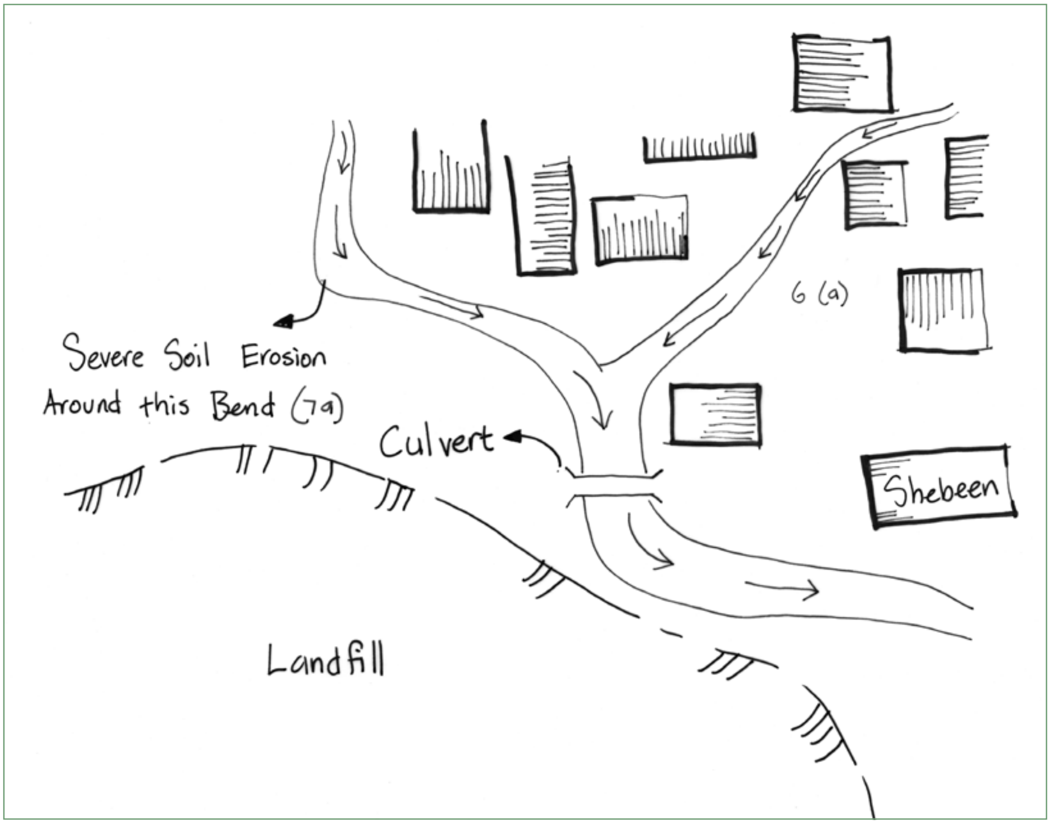
*Location*

The satellite image in Figure 4.15 shows the location of Site 2. This site is located fairly close to Site 1, such that the drains originate in the same street. However, instead of leading to the mini-wetland as in Site 1, the drains in Site 2 lead to a larger drain emptying into the main watercourse. This drain was clogged with rubbish during the first site visit. Figure 4.16 shows a schematic diagram of Site 2 before the interventions were introduced.

**Figure 4.15:** Satellite image of Site 2 location

**SOURCE:** Diepsloot, 25°93’26.29” S and 28°00’94.83” E, Google Earth (2015)

**Figure 4.16:** Schematic diagram of Site 2 before any interventions were introduced




*Visual inspection of Site 2*

There were no immediately visible attempts by households to manage surface water and only two residents expressed any real interest in the project. Householders felt as though interventions should rather come from municipal bodies.

Site 2 is located in close proximity to a tarmac road, which means that some of the waste in this area is from passers-by or people not residing within this area. Residents in the area also dumped domestic water into the channels and landfill areas even during the interventions, thus slowing down the pace of the intervention.

The informal landfill (Figure 4.18) in close proximity to the site was identified as a source of concern by residents.

**Figure 4.17:** Gullies eroded between informal dwellings (photograph of point 6a in Figure 4.16)

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

**Figure 4.18:** Large clogged stormwater drain running through the rubbish dump and into the river

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

*Addressing the community's priority needs*

Before working on this site, WASSUP was appointed to repair the toilets on the street to address the community's priority needs. WASSUP was initially mandated to repair three out of six of the toilets, taps and drains using robust, commercial-grade materials, but ended up repairing a fourth semi-operational cistern by replacing all internal parts. The street now has four working ablution facilities. There was some fear that the sewerage line, if not working optimally, might undermine a GI intervention, as residents informed WASSUP of some problems with blockages. This contributed to the decision to repair those particular four toilets and not the ones closer to JB Marks Road. In subsequent visits, residents communicated that it was much better for the toilets to be working, and offered ideas on how to rectify other problems.

A few residents took the initiative to show the researchers the various problems occurring at Site 2. The residents communicated that the various drains from the street to the large rubbish-filled drain require regular clear-up that cannot be done by hand – a task beyond the scope of this project.

*Sustainable urban drainage interventions*

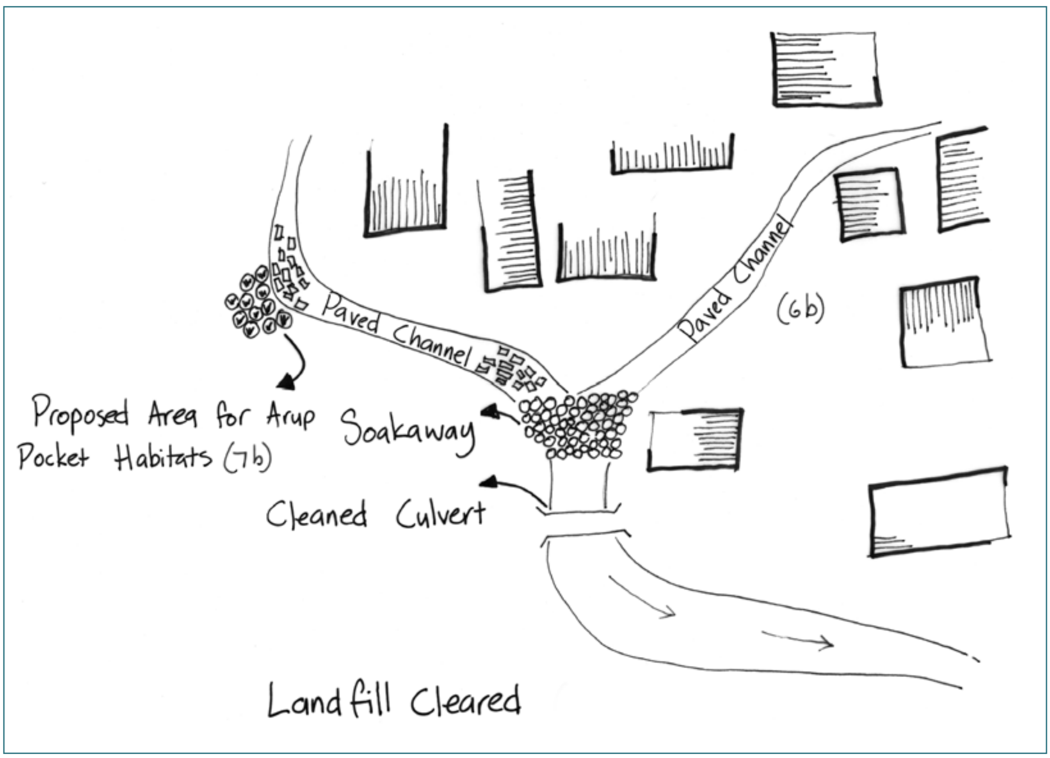
Site 2 has three eroded gullies between informal dwellings, which became key points for implementing SUDS interventions. The eroded gullies all combine at a point as shown in Figure 4.16. The water was initially recorded as being high in volume and turbid with algal growth in areas. These channels are directly adjacent to dwellings and the nearby landfill, which pollutes the exiting water through leaching. The health issues around this area required stormwater runoff reduction and improved water quality.

The most prevalent intervention implemented by the project team in this area is the alteration of the eroded gullies into a semi-pervious channel lined with loosely packed rubble and vegetation on either side. The introduction of the rubble into the channel allows for partial infiltration of runoff water and reduced erosion and scouring. The introduction of vegetation is expected to reduce the water velocity, further reducing the erosion and allowing more contact time between the soil area, which encourages infiltration. The plants also act as a filter for debris that is carried by runoff water.

The two gullies on either side of the junction were paved (Figure 4.19). These semi-paved channels lead to a common point where a soakaway was installed. The soakaway encourages further filtration and reduces the erosion from water runoff. The soakaway leads to a culvert walkway which allows residents to cross over the waterway. The waterway then passes adjacent to the landfill towards the Jukskei River.

After the interventions were carried out, a reduction in water runoff was observed in both channels, indicating the success of the semi-pervious channel in improving the water management at this small scale. The visible water quality is questionable, however, as the water remains turbid and algal growth remains in portions of the channel.

**Figure 4.19:** Schematic diagram of Site 2 after interventions were introduced



The team observed severe erosion on the northern channel bend. A multi-beneficial system designed by Arup is proposed to be introduced along the outer curve of the bend to partially mitigate the erosion that occurs at this point. The Arup Pocket Habitat is a bag designed from recycled materials which can hold soil and vegetation, thereby also increasing the holding capacity of runoff. The vegetation introduced is expected to filter debris and pollutants while the soil retains a portion of inflowing water. The bag itself is durable and weather resistant, thus reducing the velocity of runoff.

Maintenance involves ensuring that bricks don't come loose, and that litter and silt are cleared routinely along the channels and soakaway. Additionally, it is imperative to ensure that the culvert is kept clear.

**Figure 4.20:** Gullies paved and cleared of litter (photograph of point 6b in Figure 4.19)

**PHOTOGRAPH** by Anne Fitchett and Jennifer van den Bussche

*A reduction in water runoff was observed in both channels, indicating the success of the semi-pervious channel in improving the water management at this small scale*

## Water quality analysis

To quantify the influence of the SUDS intervention on runoff management and quality at the specific site, water quality tests were performed by comparing water samples before and after the interventions were implemented.

Water quality is one of the three pillars of the sustainable urban drainage model, the other two being a controllable volume of flow and environmental amenity (Charlesworth et al., 2003). Adequate water quality is essential for human and environmental health (Mafunganyika, 2011; Richards et al., 2007). Poor water quality and sanitation are catalysts for epidemics and infections, becoming of importance when considering a settlement such as Diepsloot, where basic services and infrastructure that help to manage these risks are lacking (Carruthers, 2008). However, the most impending threat is from consuming vegetables or livestock that have been contaminated by the polluted water (Richards et al., 2007).

Water quality tests were conducted to assess the impact of the various interventions on various water quality measures. The water quality tests were analysed by considering the target quality levels set by the South African Water Quality Guidelines (SAWQG) for Domestic Use (Department of Water Affairs and Forestry [DWAF], 1996a) and those of Aquatic Ecosystems (DWAF, 1996b). The target quality levels quantify a 'no effect range' for a particular constituent which would cause no adverse health effects or not threaten aquatic ecosystems.

Lotic systems (systems that carry moving water) have historically provided vital resources for human settlement; freshwater ecosystems serve us by not only providing potable water and food but also by supplying the agricultural, industrial and recreational sectors. The findings based on the SAWQG for Aquatic Ecosystems aid in understanding the environmental threat posed to the Jukskei River.

The runoff quality can quantify the effects of urbanisation to the already endangered wetland and the aquatic ecosystem within the watercourse. The effects, if negative, are of concern for not only this portion of the Jukskei, but also for all the receiving locations downstream.

### Water quality parameters

A range of water quality parameters were considered in the water quality analysis, including pH levels, conductivity, nutrients and chemical oxygen demand (COD). The source of each parameter (or how it was introduced into the system) has been considered as well as the negative effects that would be experienced by residents and the aquatic ecosystem if contamination of these parameters occurred. Because of financial limitations, *e. coli* was not tested.

#### *pH levels*

The pH of water is used to specify the acidity or alkalinity of the solution. The pH uses the concentration of hydrogen ions (H+) as a measure, with a value of 7 being neutral. An increase in H+ results in a decrease in the pH and signifies an acidic solution. Conversely, a decrease in H+ results in an increase in the pH and signifies a basic (alkaline) solution (DWAF, 1996a).

The pH of the water can be affected by various anthropogenic factors, the most relevant to Diepsloot being temperature, effluent, acidic precipitation and runoff. The pH of water can affect its taste and if the pH increases too much, the increased alkalinity can make the liquid corrosive and toxic. The DWAF (1996a) further explains pH by highlighting that adverse health impacts to humans or ecosystems are difficult to quantify from the pH of water. Rather, these impacts become evident due to the influences of the pH, such as metal ions from corrosive water. The DWAF (1996b) shows that the most detrimental effects on ecosystems occur when the water is acidic, but an inevitable decrease of biodiversity will be experienced by extreme alkaline conditions.

#### *Conductivity*

Conductivity is the ability of water to carry an electric current. This is an indication of the concentration of ions in the water, typically from alkalis, chlorides, sulphides, carbonates, calcium and magnesium. Aquatic life, both animals and vegetation, is adapted to a certain range of salinity, beyond which (lower or higher), these fauna and flora may die.

*Nutrients*

Nitrates, phosphates and ammonium are nutrients used by plants, which can, in high concentrations, have adverse effects on aquatic ecosystems. These nutrients are vital constituents for ecosystems because plants take up these nutrients and utilise them for growth and reproduction. Given their importance to plants, these nutrients are found in large quantities in fertilisers, where they are then spread by irrigation and stormwater runoff from agricultural land. These nutrients are also in human and animal excrement, which enter the water system from septic tank failures and wastewater treatment locations (World Health Organization [WHO], 2011).

The main effect of high concentrations of nitrates is felt by the surrounding ecosystems through eutrophication. Eutrophication takes place where there is an excess of nitrate nutrients causing algae growth (algal bloom) and results in oxygen depletion when the algae dies. The algae can be toxic in nature and the oxygen-reduced water can kill fish and invertebrates (DWAF, 1996b).

*Chemical oxygen demand*

COD measures the amount of organic matter present in water by analysing the oxygen used. High concentrations of organic matter (i.e. dead plant/animal matter that is in the process of decomposing) are found in wastewater and effluent. Once the organic matter enters the water, a chemical decomposition by oxidisation will occur (Selectech, 2013). Oxidation within water uses dissolved oxygen, which is essential for the respiration of aerobic organisms in aquatic ecosystems (DWAF, 1996b). The COD measurement equates the amount of oxygen used to the amount of organic matter. If the organic matter, and thus waste, discharged into the watercourse is high, the oxygen levels will be depleted, creating the possibility of eutrophication.

## Samples

Various water samples were taken at each of the intervention sites. Figure 4.21 combines the site layout of Site 1 and points at which water samples were manually collected before (B) and after (A) interventions were implemented. The same is done for Site 2 (see Figure 4.22). A legend in each schematic diagram describes the points of water sampling at both sites.

Given that temporal variations of the water quality parameters will occur, it was ensured that the samples before and after the interventions were taken in similar circumstances. The first samples were taken in early summer and the second in late summer. Both sample sets were taken on an overcast day, at a similar time and approximately three days after a rainstorm event. The samples of approximately 75 ml were collected in 150 ml clear plastic containers that had been rinsed with deionised water. They were transported in a cooler box surrounded by gel ice-blocks and tested within three weeks of sampling.

The water quality of the samples was tested in the water quality laboratory at the University of the Witwatersrand.

First, the pH and conductivity of the water were tested by inserting a digital pH test meter and an electrical conductivity meter into the solution until readings stabilised. Throughout the measurement of conductivity, a homogenous mixture of the solution was ensured by using a magnetic stirrer.

Second, the concentrations of phosphates, nitrates and ammonium as well as the COD were tested using Spectroquant® test kits. Each test used a colour range for initial readings of the constituent concentration. Thereafter, the vials were placed within the Spectroquant® analyser. The input of the test conditions allowed the exact concentration of these constituents to be produced.

*Water samples before and after the interventions were taken in similar circumstances*

**Figure 4.21:** Site 1 locations where water samples were obtained

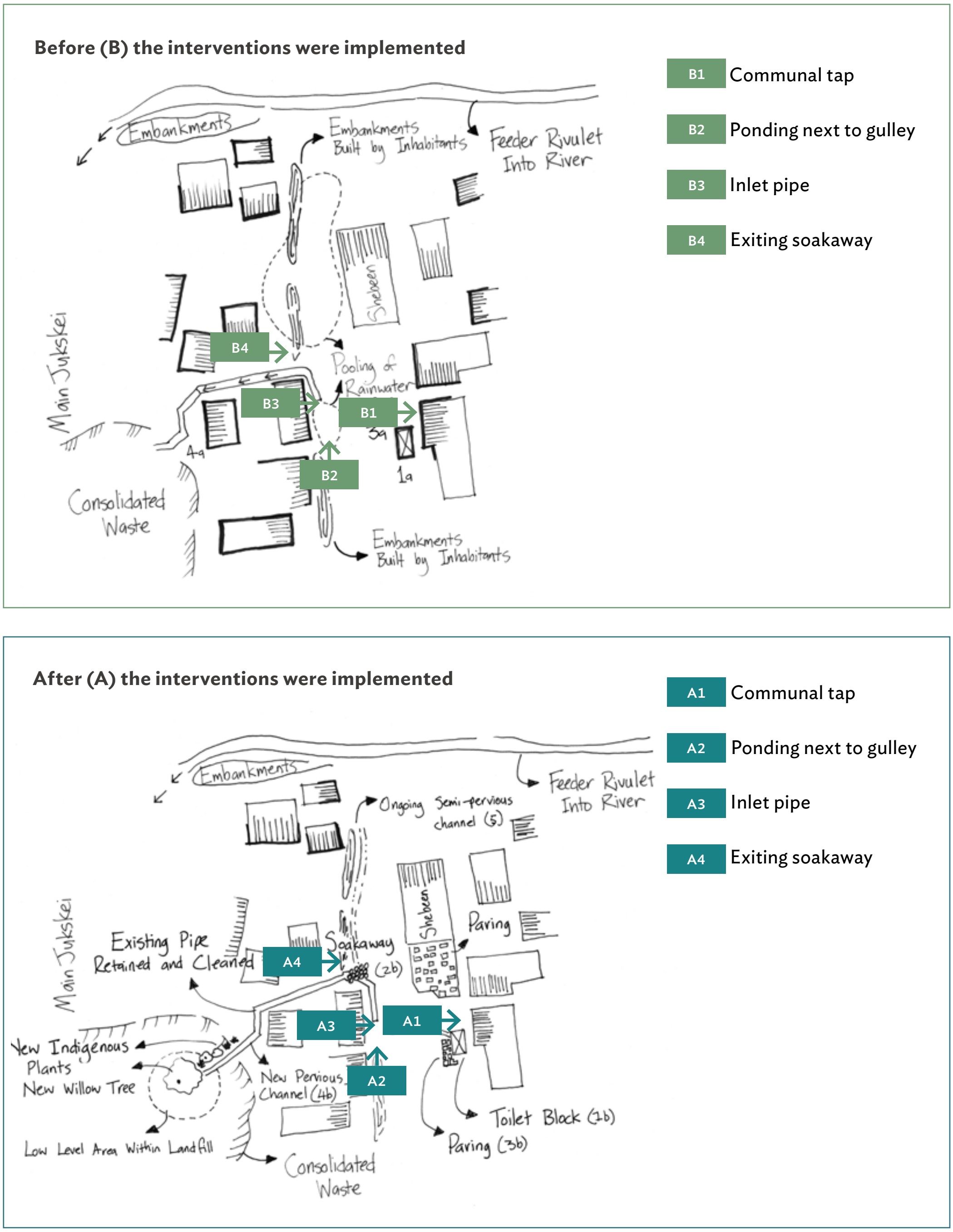
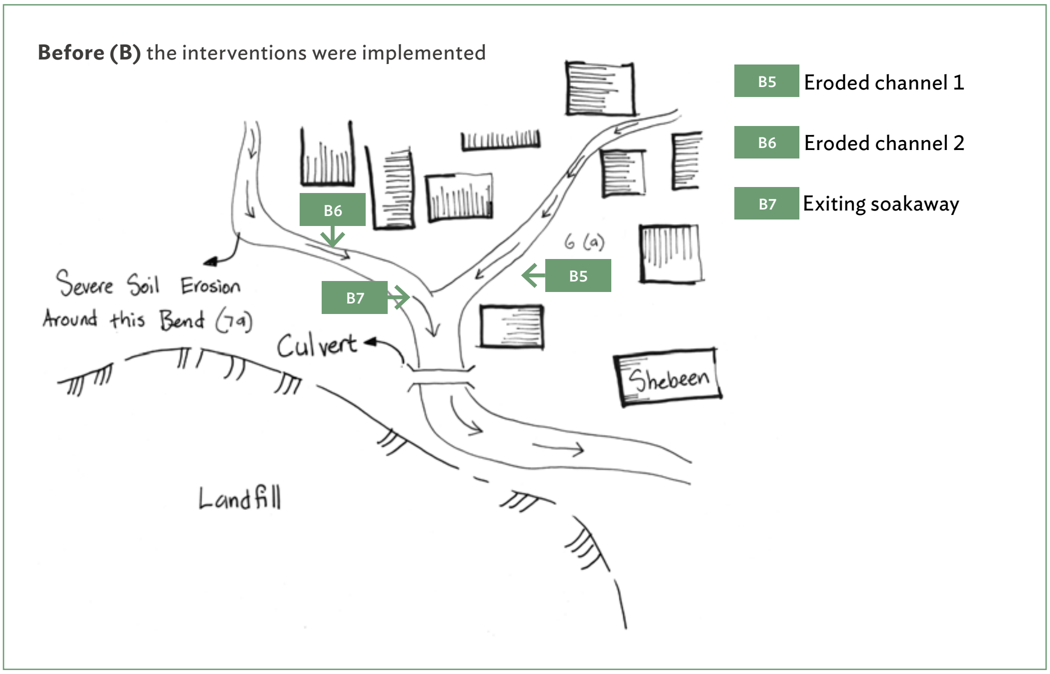
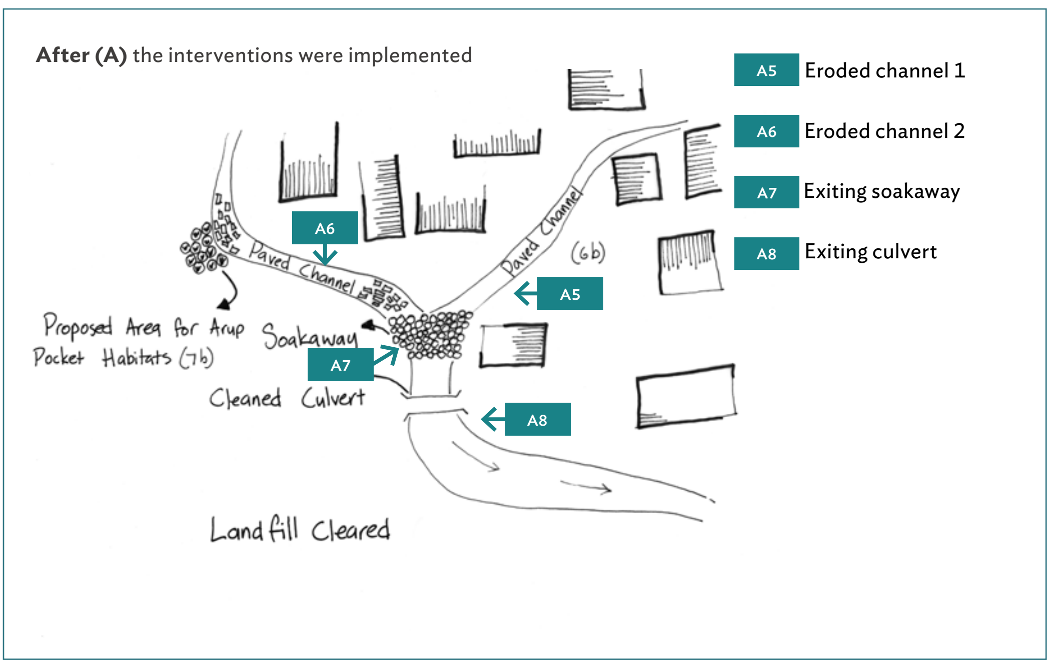


**Figure 4.22:** Site 2 locations where water samples were obtained



## Results

The water quality was analysed by two comparison methods. The first considered the quality of the surface water with respect to the SAWQG, which helped quantify the effect of rapid urbanisation and the lack of provision of infrastructure. These results help form a recommendation about the necessity of water quality improvement for the residents and the surrounding environment. The second water quality analysis investigated the effects of the constructed interventions.

### *Runoff water quality*

The SAWQG for Domestic Use measured the water samples against the standards needed for all domestic water, such as drinking, personal hygiene, washing and gardening (DWAF, 1996a). The comparison to safe drinking water is effective for evaluating the quality of the samples. Although the water in the area is not currently being utilised for these activities, residents face potential risks from the accumulation of water in solid and liquid waste disposal sites and attenuated water from rainfall events which lead to contamination of the water. The risk of contamination is heightened by contact activities, such as children playing in the water.

Table 4.1 shows the target ranges for the quality parameters analysed as set out in the SAWQG for Domestic Use (DWAF, 1996a) and for Aquatic Ecosystems (DWAF, 1996b). The guidelines for the COD have been sourced from the Department of Environmental Affairs and Fisheries (DEAF, 1984). Table 4.1 shows the results of both Site 1 and Site 2 before and after the interventions for each of the water quality parameters. The table also identifies whether the samples adhere to, or violate, water quality guidelines in each case. Each row in the table represents a specific water quality parameter and its respective water quality guideline, and the results of each sample. Water quality parameter measurements that violate the SAWQG for Domestic Use standards are highlighted in yellow, while those which violate the SAWQG for Aquatic Ecosystems standards are highlighted in green.

The quality parameters are discussed individually below, including possible reasons for the results and to consider the effects that the parameters could have on human and natural ecosystems. Alongside the investigation of the water conditions in Diepsloot, there is a comparison with changes resulting from the interventions.

### *pH Levels*

The results show that the pH levels from the surface water within the two sites were mostly within the acceptable domestic use standards (i.e. not highlighted yellow) (Table 4.1). However, samples tended to be at the higher end of the acceptable range for domestic use.

The pH violated the aquatic ecosystem guidelines at all sample locations after the intervention in Site 1 and in three of the sample locations in Site 2. The alkalinity readings, however, are not on the extreme end, but marginally above the limit. The higher pH indicates harder water (Oram, 2014), but poses no direct health risk.

The findings indicate that pH levels increased after the interventions. Since pH values increased throughout the entire system, it is likely that the pH of the catchment increased. However, the pH readings consistently decrease as water moves downstream through the system in both Site 1 and Site 2.

*These results help form a recommendation about the necessity of water quality improvement for the residents and the surrounding environment*

**Table 4.1:** Site 1 and 2 water quality results. Green shaded blocks indicate samples that violate the Aquatic Ecosystem guidelines, and yellow shaded blocks indicate samples that violate Domestic Use guidelines. Blocks shaded white adhere to both Domestic Use and Aquatic Ecosystem guidelines.

| | Water quality guidelines | | Site 1 | | | | | | | | Site 2 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Domestic use | Aquatic ecosystems | Before samples | | | | After samples | | | | Before samples | | | After samples | | | |
| | | | B1 | B2 | B3 | B4 | A1 | A2 | A3 | A4 | B5 | B6 | B7 | A5 | A6 | A7 | A8 |
| pH | 6.0 to 9.0 | 6.0 to 8.0 | 7.76 | 8.01 | 7.53 | 8.39 | 8.41 | 8.41 | 8.18 | 8.2 | 7.51 | 7.88 | 7.86 | 7.53 | 8.47 | 8.24 | 8.17 |
| Ammonium, $NH_4^+$ (mg/l) | 0.0 to 1.0 | 0.0 to 7.0 | 1.7 | 5 | 0.5 | 5.7 | 0.5 | 1 | 1.3 | 2.3 | 0.5 | 0.5 | 6 | 2.1 | 3.4 | 5.8 | 5.4 |
| Nitrate, $NO_3^-$ (mg/l) | 0.0 to 6.0 | 0.0 to 0.5 | 0.5 | 0.9 | 5.1 | 5.3 | 0.5 | 4 | 0.5 | 0.5 | 4.4 | 5 | 0.5 | 0.9 | 5.4 | 0.5 | 0.5 |
| Phosphate, $(PO_4)^3$ (mg/l) | – | 0.0 to 5.0 | 0.5 | 1.2 | 0.9 | 5.5 | 0.6 | 0.5 | 0.5 | 0.7 | 0.7 | 0.6 | 1.1 | 0.6 | 1.3 | 0.9 | 0.8 |
| Chemical oxygen demand (mg/l) | – | 0.0 to 75.0 | 32 | 178 | 56 | 1 289 | 25 | 74 | 36 | 81 | 80 | 33 | 131 | 33 | 223 | 72 | 67 |

*Ammonium*

The ammonium concentrations all fall within the acceptable range for aquatic ecosystems. This range, however, is violated for domestic use (Table 4.1). This is advantageous as the negative impacts on aquatic ecosystems can result in a vast reduction in the animal and plant populations (DWAF, 1996b).

Although domestic use target violations were common in the samples, the effects on humans are not severe at the recorded concentrations, only affecting the taste and odour of the water (DWAF, 1996a). Site 1 shows largely reduced concentrations of ammonium in the system, indicating an improved ammonium concentration level in the catchment. Site 2 surprisingly shows a great increase in the ammonium readings after the implementation of the system. This increase in ammonium levels at Site 2 can be attributed to a point source of pollution nearby the site, especially when considering the reduction seen at Site 1. Sample A8 at Site 2 does, however, show that the soakaway in Site 2 is effective at reducing the ammonium concentration.

The reduction of ammonium levels in both sites is indicative of the efficiency and effectiveness of the SUDS interventions introduced into these sites.

*Nitrate*

All samples are below the upper domestic concentration limit of 6 mg/l, with the highest being 5.4 mg/l (sample A6). If the concentrations were to exceed this limit, methaemoglobinaemia (a life-threatening condition which inhibits oxygen circulation) is possible in infants (DWAF, 1996a).

Most of the samples fall outside of the acceptable range for aquatic ecosystems despite the reduction in nitrate levels in both sites in the post-intervention samples (Table 4.1). In Site 1, the pre-development nitrate concentrations were higher than the acceptable range with a clear increase in the downstream direction, the outlet exhibited values which were approximately ten times higher than the target. The post-developmental samples show reduced pollution levels; a spike in concentration seen at A2 is effectively reduced by the permeable paving and pipe, so much so that the outlet of the system has an acceptable concentration. A similar reduction occurred at Site 2 as water flowed through the permeable paving into the soakaway.

The SUDS interventions installed at Site 1 and Site 2 proved effective in reducing the nitrate concentrations and thus the risk of eutrophication of the Jukskei.

*Phosphates*

The health risk of high concentrations of phosphate is pertinent to aquatic ecosystems, and the maximum 'no effect' value is 5 mg/l. Table 4.1 indicates that Site 1 had acceptable phosphate concentrations with the exception of the outlet; this is most probably due to a point source of pollution. DWAF (1996b) explains that this amount of phosphate in the Jukskei would produce excessive growth of aquatic plants and algal blooms. The system installed in Site 1 reduced the phosphate concentrations throughout and, at the outlet, the concentration was reduced by a remarkable 69%, yielding an acceptable quality. Although all samples in Site 2 were within the acceptable range, the effectiveness of the SUDS intervention should be noted. A reduction in phosphates can be seen as the water travelled down the permeable paving; a further reduction was then experienced when the water passed through the soakaway.

*Chemical oxygen demand*

As discussed previously, the COD measures the amount of organic matter present in water. High concentrations of organic matter reduce the oxygen available for aquatic plants and species.

The pre-intervention samples had COD readings that were higher than 75 mg/l at the outlets, posing a risk of eutrophication. Site 1 exhibited an astoundingly high reading at the outlet (B4=1 229 mg/l), approximately 16 times higher than the target. Similarly, Site 2 showed an oxygen demand of nearly double (B7=131 mg/l). These high values can be attributed to the waste in the area, such as cans, tins and building waste.

The installation of the SUDS intervention showed a positive effect on the COD values. Site 1 exhibited a reduction in COD at all points of measurement, the most notable being a 94% reduction at the outlet (sample point A4). Although the outlet is still above the acceptable target, it is only marginally so (81 mg/l). Site 2 also shows the reduction of COD, to the extent that the outlet is now producing water considered safe for aquatic ecosystems.

## Discussion

The outcomes of this research can be considered from three angles: the effects of the reduction of surface water on social amenities; the water quality consequent on the interventions; and the social learning associated with adaptive co-management processes. It is interesting to note the considerable variation between the two sites in many of these aspects.

The rapid urbanisation of Diepsloot, coupled with the lack of adequate infrastructure to accommodate stormwater runoff and waste disposal have been shown to have negative effects on the runoff water quality and, ultimately, on the quality of the Jukskei River. Many of the water quality parameters analysed before the SUDS interventions showed test results that were higher than the target ranges for domestic use and aquatic ecosystems in at least one point in the system. This affirms the need for a sustainable drainage solution which will not only reduce the volume of runoff but also improve the water quality (Ellis et al., 2012). A post-intervention site visit revealed that the surface water volume at both sites had reduced considerably as a result of the interventions. This indicates that the use of pervious channels and soakaways can play a useful role in minimising the standing water that characterised both sites prior to this study. Water running through the SUDS elements is mostly below the upper level of the brick paving, leaving a dry surface in the lower portions of the channels. A potential negative consequence of the reduced flow of surface water is on the dilution of pollutants, which could result in increased concentrations of some water quality parameters.

Throughout the period of the action research, there was a general feeling that the water quality would not be substantially improved given the close proximity of both sites to an extensive informal landfill. It was thought that the leachates from the landfill and surface littering would have such a high level of contamination on the surrounding downstream areas that any small-scale intervention would be insignificant. While this was the case in some instances, there was nonetheless improvement in water quality at both sites. This strongly speaks to the viability of small-scale localised interventions in improving water quality despite conditions not being optimal. In contrast with conventional piped stormwater systems that merely remove the surface water to another location, whether a natural watercourse or a treatment plant, the very simple and inexpensive SUDS implemented in this study not only addressed the removal of the surface water, but improved the water quality at the same time. This is crucial in confirming the applicability of SUDS to the context of informal settlements in South Africa (Ellis et al., 2002, 2012; Parkinson et al., 2007). This is consistent with the global literature on SUDS as a means of ameliorating pollution (Charlesworth et al., 2003; Ellis et al., 2002, 2012; Jones & Macdonald, 2007; Parkinson et al., 2007).

Another important finding of the research lies in the adoption of local practices with regard to recycling. Each of the interventions evolved from experimentation with materials available in the immediate area, mostly in the form of construction waste dumped in the informal landfill. The material of choice was broken bricks, since they are structurally and environmentally robust, versatile, and easy to use even by inexperienced workers. This approach requires an inversion of the conventional engineering method, in which a problem is defined and analysed, a solution is designed with pre-determined materials and specifications, followed by implementation to the specifications. When this process is inverted, the design evolves from an interaction of a range of possible types of intervention and the materials at hand. In some cases, the intervention can be improved through the inclusion of purchased materials, such as a small piece of geotextile membrane for the soakaway at Site 1. However, often the problem can be solved through the same ingenuity prevalent throughout the informal settlement (Fitchett, 2014).

From the purely social perspective, the social dynamic at the scale of a cluster of households appears to play a significant part in the success of the implementation, adaptation phase and ongoing maintenance that is critical to the effectiveness of any SUDS system. Site 1, located at the end of a lane, appears to have strong social cohesion, with at least one of the residents standing out as a natural leader and initiator. All of the families within this site were enthusiastic about the project from the initial discussions through to the present, as evident in the ongoing extensions and improvements that the residents spontaneously carried out. An important factor could be that the only 'outsiders' that regularly frequent this site are a handful of 'regulars' to the tavern next to the communal toilet. The small amount of litter in the lane is probably associated with the tavern. On the river side of the site, there is still some evidence of domestic dumping, but this is at a fairly small scale. It is not clear whether this is from the residents, as there is no obviously convenient waste disposal option given the distance from the formal road, or whether the waste is dumped by people from outside the immediate area.

By contrast, the dynamic at Site 2 was extremely fragmented. Only two of the residents appeared to have any real interest in the project; most others indicated that surface water management was low on their list of priorities. This view is supported by the frequent experience of residents dumping buckets of domestic wastewater into the channels and onto the landfill area, even as work on the SUDS interventions was in progress. This inhibited the construction that required extensive drainage of the channels before work could commence. The perceptions of the residents at Site 2 were that their major concern was around the extensive informal landfill on the northern side of the study area. They also voiced the view that solid waste removal, surface water management and similar issues should be addressed by the municipality rather than the community, paralleling the findings of Armitage et al. (2009).

The location of Site 2 may be significant, both in determining the social dynamic and in shaping attitudes. Its proximity to a formal tarmac road, near one of the few bridges across the Jukskei River, encourages a large number of non-residents into the area. It is also a short-cut pedestrian route from the formal road into the adjacent areas. It appears that people who are not residents of this particular site regularly use the area for dumping domestic waste. The lane off the tarmac road is also wide enough for small trucks to gain access, thereby facilitating the dumping of construction waste. This breeds a sense of despondency in the residents, in that any intervention on their part is immediately vulnerable to these external factors and role-players. Despite this, one of the residents has shown initiative in adopting some of the possible interventions, but only immediately adjacent to his own dwelling.

One practical finding of the research is the interrelationship between surface water and litter in an informal settlement. These each have the potential for undermining interventions of the other. Litter rapidly renders a stormwater intervention dysfunctional, whether for SUDS or a conventional solution. Conversely, surface water that is not adequately managed provides a trap for litter, rendering relatively inoffensive 'dry litter' into a stagnant morass. This indicates that any intervention that attempts to manage either of these two problems should address the other concurrently and in an integrative project.

Photograph by Clive Hassall

## Conclusion

The objectives of this study focus on whether interlinked SUDS interventions can improve the surface water quality and surface water drainage in an informal settlement context, specifically Diepsloot in the CoJ. The crux of the project focuses on the holistic integration of both human and material resources in an attempt to improve quality of life and simultaneously contribute to improved environmental quality. The approach undertaken in this study combined principles and processes of action research and adaptive co-management as a means to evolving adaptable interventions that can respond to the ever-changing physical context of an informal settlement, and nurture self-management of the interventions by the residents of the immediate locality of the two study sites.

The community is exposed to many health risks from contaminated water sources and pollutants that are discarded into eroded gullies and channels (Carruthers, 2008). One of the benefits of the introduction of SUDS is the improved water quality of the runoff, which reduces the health risks associated with the polluted water. From the findings of the tested water samples before and after the SUDS interventions were made, some reduction in pollutants can be seen. This reduction, although in many cases still violating domestic use or aquatic ecosystem limits, is indicative of the potential for SUDS interventions to improve surface runoff quality. Looking at the larger scale of the informal settlement, it can be argued that a comprehensive GI network could substantially improve the water quality, thereby reducing the risk and spread of water-borne illnesses associated with poor sanitation.

The widespread introduction and integration of SUDS interventions in an informal settlement would require a complex, multi-disciplinary approach because of the social, environmental and economic dimensions (Parkinson et al., 2007). Communities from different areas within the settlement can be expected to have differing priorities, views of the environment and attitudes towards the interventions. As seen in this project, some community members took on a very committed role in initiating SUDS within their area, especially after the first interventions were completed. At the second site, the community commitment was much lower, with fewer volunteers and an ever-changing spectator contingent. This variability in community involvement may be complex. However, through the positive interaction with communities following adaptive co-management, action research and addressing community needs, it is argued that if a bottom-up participation method is implemented, the community can become committed to driving the introduction and integration of SUDS as a supplement to the existing conventional drainage systems.

Recurrent themes in this chapter are participation, engagement and the role of the community in the success of the project. It has been recognised that top-down participatory approaches do not address community needs and little trust is gained (Hayward et al., 2004). In this study, a firm relationship with the community was established from the outset, which provided a platform for knowledge exchange. It is encouraging to observe that community members began initiating similar interventions at small scales to improve their residential areas. Their self-initiated SUDS projects indicate that the participatory approaches used were successful in encouraging the community to actively resolve their stormwater problems, and that the knowledge exchange was effective.

The SUDS interventions that were implemented in this study have proved to be effective to a certain extent. It is unrealistic to expect SUDS to solve the stormwater issues of the area entirely; however, the GI introduced does indicate its effectiveness at reducing the volume of runoff, which, in turn, indicates the potential to alleviate the excessive volumes of stormwater that were not accommodated by conventional 'grey' infrastructure. The concrete systems were designed for a pre-densification stormwater runoff scenario and the intention of introducing SUDS into the environment is to alleviate the significant increase in runoff volume due to the rapid densification of the area. As SUDS initiatives expand, the interlinking between the green and grey systems could substantially reduce the excessive flooding in the informal settlement. Any future SUDS interventions should be designed to integrate with the conventional stormwater drainage


systems to reduce the load on the conventional systems, thus reducing the risk of structural failure of the conventional drainage system.

As with any intervention, the success of implementing SUDS in informal settlements is strongly dependent on maintenance and follow-up. The community within which the interventions are introduced should be enabled to understand how the system works and identify the areas that spark concern throughout the project. Once the implementation of the project is carried out, the benefits seen by community members are expected to encourage custodianship of the intervention.

Informal settlements, as seen in Diepsloot, are characterised by health and safety crises because of inadequate services and rapidly growing populations. The extent of issues in these areas can be overwhelming, especially where significant environmental and social injustices intersect. In light of this context, although the SUDS interventions were small in scale and could not solve the systemic problems in the area, the successes that were evident in this study, including community buy-in and engagement, are significant.

*Although the SUDS interventions were small in scale and could not solve systemic problems, the successes evident in this study, including community buy-in and engagement, are significant*

Photograph by Clive Hassall

constructed wetlands

# Chapter 5

# Atlas Spruit green infrastructure flood relief scheme: Costs and benefits

*STUART DUNSMORE, RAISHAN NAIDU AND MARCO VIEIRA*

## Key points

- This investigation considers a flood relief scheme in Atlasville as a case study to demonstrate the functioning, costs and benefits of green infrastructure (GI) projects. The Atlas Spruit flood relief scheme set out to address serious flooding, but, in the process, it was adapted to enhance social, ecological and economic benefits for the surrounding community.
- The chapter compares the GI solution that was implemented in Atlasville with the design of an equivalent grey infrastructure option. Each of these options is described in detail, including scheme designs and modelled impacts, and their respective costs and benefits are assessed and compared.
- The GI flood relief scheme was designed to achieve 100-year flood relief through a combination of widening the channel, deepening it by removing the silt build-up, and improving the hydraulic efficiency in the main part of the channel. The GI scheme also preserved and, where possible enhanced, the public park and recreation facilities adjacent to the spruit, and provided ecological enhancement.
- The grey infrastructure scheme was designed for the same flood capacity (100-year) as that achieved with the green scheme. The scheme included a concrete channel designed to contain the more frequent, smaller flood events, with a vegetated floodplain that would help contain 100-year flood events.
- The cost–benefit analysis includes a range of components including the capital and maintenance costs, community responses to the GI scheme, ecological habitat and property price analysis.
- The analysis revealed that the capital cost of the green scheme is, at worst, equivalent to a grey infrastructure scheme with the same primary service capability.
- Costs for required maintenance, including grass cutting, reed removal or management, removal of deposited sediment, and erosion control and bank stabilisation are anticipated to be approximately equivalent for the green and grey schemes.
- The green scheme outperforms the grey scheme in terms of ecological enhancement because of the habitat improvement observed in the in-stream condition, which would not be possible in the grey scheme.
- The community response to the scheme has been positive, with a preference stated for the green scheme.
- Although flood relief, which is equivalent in the two schemes, is the primary benefit of the scheme and will influence property values, there is evidence in favour of the green scheme adding to property values.
- This analysis provides evidence that not only can a green infrastructure project provide equivalent flood relief at a comparable cost to a traditional grey infrastructure option, but it also provides a range of additional benefits and services that a grey infrastructure alternative cannot.

## Introduction

In South Africa, traditional grey infrastructure for stormwater is still the standard, though there is increasing interest in sustainable drainage methods which can incorporate green infrastructure (GI) solutions. Standards for sustainable urban drainage systems (SUDS) are still developing for South African conditions. For example, the first version of the City of Johannesburg (CoJ) Stormwater Design Manual (CoJ, 2019) will still take some time to gain traction amongst developers and practitioners. As a result, there is reluctance among government and the private sector in Gauteng to develop GI projects without clear standards and evidence of how new approaches function compared to more familiar approaches. In this context, it is useful to apply cost–benefit analysis (CBA) methods to pilot projects and case studies to help build a reference base for developing such standards. CBA is a methodology that is used to support decision-making and, in particular, infrastructure development decisions. In urban drainage, it would typically be applied to capital expenditure projects above a threshold cost, though it may not be applied to stormwater infrastructure that follows standards approved by municipalities.

This investigation considers a flood relief scheme in Atlasville as a case study to demonstrate the functioning, costs and benefits of GI projects. This contributes towards the development of necessary standards and motivating for greater uptake of a GI approach. The Atlas Spruit flood relief scheme, located in the northern region of the City of Ekurhuleni, was developed in line with SUDS principles. It is a scheme that set out to address serious flooding, but, in the process, it was adapted to enhance social, ecological and economic benefits for the surrounding community. The investigation outlines the scheme, which was based on a GI approach (from here on, the 'green scheme') and its background, and it compares the capital cost of the scheme with an equivalent grey infrastructure solution. It also investigates the social, economic and ecological components of the scheme, drawing on the experience of two years of vegetation establishment and community use since the completion of Phase 1 to assess the performance of these components and, where possible, to assign a value to them.

Applying a CBA to municipal capital investment decisions requires the right kind of data to support quantitative analysis. CBAs are sometimes conducted in the planning phase of a project, and the content is adapted and developed to suit the decision-makers or the funders (i.e. CBAs are always context specific). At the start of a project, all of the data necessary for a full CBA may not be readily available. In addition, a good reference database is important for CBA applications and it generally takes municipalities some years to develop the necessary data once the preferred format of the CBA is selected. Hence, initial CBAs typically start with what data are available and, in most cases, they focus on the capital cost of infrastructure projects. This case study adopts this approach, but also considers a range of the wider, potential benefits of the scheme.

There is a clear indication that many of these additional benefits are already emerging in the Atlas Spruit scheme. However, there are also warning signs that the scheme, as with any traditional grey infrastructure solution, needs maintenance to sustain the multiple benefits. The investigation looks at these issues and also identifies aspects of the project that could have been improved upon to enhance the cost–benefit ratio. The premise of a CBA is that infrastructure is worth investing in (or it is worth spending ratepayers money on) when the value of the benefits exceeds the cost of the scheme.

Flood management, which is the primary focus of this case study, is a key part of urban drainage. Flood management projects generally require more space than other drainage assets and, therefore, there is usually more opportunity for a flood scheme to provide additional GI benefits through careful planning of the additional space. Flood relief schemes are required when poor catchment planning and development control leads to increased flood risk. In such cases, a drainage solution must be retrofitted to mitigate the increased flood risk. Flood relief schemes are usually linked to urban streams and rivers that, in the context of metropolitan areas of Gauteng, are likely to be in a degraded state. With the increasing focus on sustainable environmental solutions, flood relief schemes are well suited to serving the broader functions of green assets.

This chapter focuses on services such as stormwater conveyance, flood management, provision of public amenity (parks) and ecosystem services, which the Atlas Spruit flood relief scheme has sought to provide. The provision of multiple services is central to the performance of GI and will define its status as a municipal asset.

This chapter contributes to building the case for adopting a GI approach by undertaking a CBA of the Atlas Spruit flood relief scheme. The chapter compares the GI solution that was implemented in Atlasville with the design of an equivalent grey infrastructure option.[1] Each of these options is described in detail, including scheme designs and modelled impacts, and their respective costs and benefits are assessed and compared. The CBA includes a range of components including the capital and maintenance costs, community responses to the GI scheme, ecological habitat and property price analysis. These components are then used to draw conclusions about the relative merits of the GI option versus the designed grey infrastructure alternative. This analysis provides evidence that not only can a GI project provide equivalent flood relieve at a comparable cost to a traditional grey infrastructure option, but it also provides a range of additional benefits and services that a grey infrastructure alternative cannot.

Before going into the details of the Atlas Spruit flood relief scheme, the following section provides some background into the range of approaches that can be used to analyse and compare the costs and benefits of different investment options.

## Cost–benefit analysis

There are various approaches for assessing the costs and benefits within a CBA, which are mostly adapted to suit the nature of the project, the objectives of the CBA and data availability. CBAs can go into considerable detail when suitable data are available. The scope of CBAs needs to be carefully considered to ensure that the analysis informs decision-making as required.

The United States (US) Environmental Protection Agency (US EPA, 2013) lists a number of economic analyses that have been used to assess GI projects. Those considered relevant to application at the municipal level in Gauteng are summarised in Table 5.1.

The metrics used in CBAs are selected according to the objectives of the project. Typical costs include capital costs and life-cycle costs, although the definition of each may vary according to municipal requirements. Cost may also be broken down into a ‘per unit’ measurement relating to, for example, cubic metres of storage or milligrams per litre of pollutant removed. Costs can also be calculated for damages, or pollutant loads, for conditions greater than the design standard of the scheme. Other factors such as job losses and loss of arable land may also be significant in certain applications. The measurement of benefits is similarly varied and includes: avoided flood damage costs; avoided treatment costs; improved land values; improved visitor numbers; reduced maintenance costs; job creation, etc.

Both costs and benefits can be expanded to consider direct and indirect benefits, where the latter may arise as a consequence of the scheme (e.g. reduced traffic disruption in a flood relief scheme) rather than the original intent of the scheme (i.e. to protect property from flood damage). In the case of GI schemes where multiple services are part of the design, some of the indirect benefits can become direct benefits (e.g. improved property values).

There may also be intangible benefits that may accrue as a result of the scheme that can be difficult to quantify and assign monetary value (Penning-Rowsell et al., 2013). For example, it is difficult to measure the value of the relief of emotional stress during storm events that developed from experience and stress of the regular flooding that occurred before the scheme was implemented. Stress relief and well-being are commonly considered in CBAs for urban flood relief schemes.

1 The authors of the chapter include the engineers involved in the design and implementation of the scheme, thus many of the insights presented here draw from personal experience and knowledge of the flood relief scheme. The modelling presented in this chapter draws from the project itself and the subsequent work towards designing an equivalent grey infrastructure alternative.

**Table 5.1:** Examples of different types of cost–benefit analyses

**SOURCE:** Adapted from US EPA (2015) and Armitage et al. (2013)

| CBA type | Description | Local relevance |
|---|---|---|
| **Capital cost assessment** | This is the comparison of the cost of works, cost of land, and any other up-front costs to build a scheme. It excludes operational and maintenance costs. | It is useful in comparing one option against another, and data are more readily available through the planning and design process. It is one of the more common methods applied by municipalities in South Africa. |
| **Cost–benefit analysis** | This attempts to capture all the associated costs and benefits of a scheme, converted to monetary value as far as possible, and all reduced to net-present value (NPV). | The components of the analysis will be determined by the municipality or sector and the objectives of the assessment. For example, life-cycle costs may be narrowed to just capital costs plus operations and maintenance costs over the design life of the scheme. Usually CBAs include costs and benefits that can be easily assigned market values. However, it has long been recognised that there are additional benefits that accrue from schemes that improve the safety and well-being of communities. Increasingly, CBAs seek to include these components, quantify their values and even monetise them. |
| **Life-cycle cost analysis** | This is the calculation and comparison of all costs from acquisition to disposal of an asset. The method does consider revenues as benefits, but does not necessarily include the value of all ecosystems' goods and services, although they can be economically (not monetarily) appraised and then included. | Armitage et al. (2013) find this the most appropriate method for South Africa, as it ensures all stakeholders will have an understanding of their total commitments. Armitage proposes to use 'Damage Avoidance Costs', which applies the substitute costs principle to estimate the value of improved water quality and water flows (the alternative costs of using a grey infrastructure design to get the same benefit). It can also include land values as both costs (e.g. land purchase) and benefits (e.g. improved land values). |

| | | |
|---|---|---|
| **Cost-effectiveness analysis** | In this approach, the capital cost or life-cycle cost is reduced to a cost per unit, such as cost per cubic metre of stormwater reduction, or cost per kilogram of sediment trapped. In this way, different GI options (and grey options) may be compared. | This approach has been effective at municipal level in the US where investment performance on, say, sediment load reduction can be monitored and reported. However, it would need to be adapted for South African conditions. |
| **Fiscal impact analysis** | This approach is linked to land use, land values and therefore land revenues. It assists municipalities evaluate the return on investment of different land types and locations. | This option is relevant to GI projects that are linked to drainage and watercourses, particularly where land values are influenced by proximity to watercourses and public open space. |

The approach best suited to municipal projects is normally developed over time. A life-cycle CBA would be the initial target, but may be adapted according to fiscal or environmental targets. Life-cycle CBAs are more data-intensive and municipal databases need to be developed over time. As such, the early versions of CBAs are more often centred on capital costs comparisons. Current research by the Gauteng Department of Agriculture and Rural Development (GDARD) into the implementation of SUDS in the province point to a combination of life-cycle analysis with a multi-criteria analysis, where the latter enables a qualitative assessment of a much broader range of environmental benefits (GDARD, 2019). As the scope of services provided by GI projects in Gauteng and South Africa are developed, so the elements considered in CBAs will be expanded. Aspects such as water resource management, water quality improvement, temperature control (urban heat island mitigation), carbon sequestration and others may be included in time. Many of these will be site and project specific.

Irrespective of the CBA approach that is adopted, the cost–benefit ratio is calculated for each scheme option according to the costs that the scheme will incur against the value of the benefits that the scheme provides. Hence each scheme option will have its own cost–benefit ratio that is compared to the ratios of other options (if there is more than one option considered[2]). The scheme with the best ratio would point to the best investment.

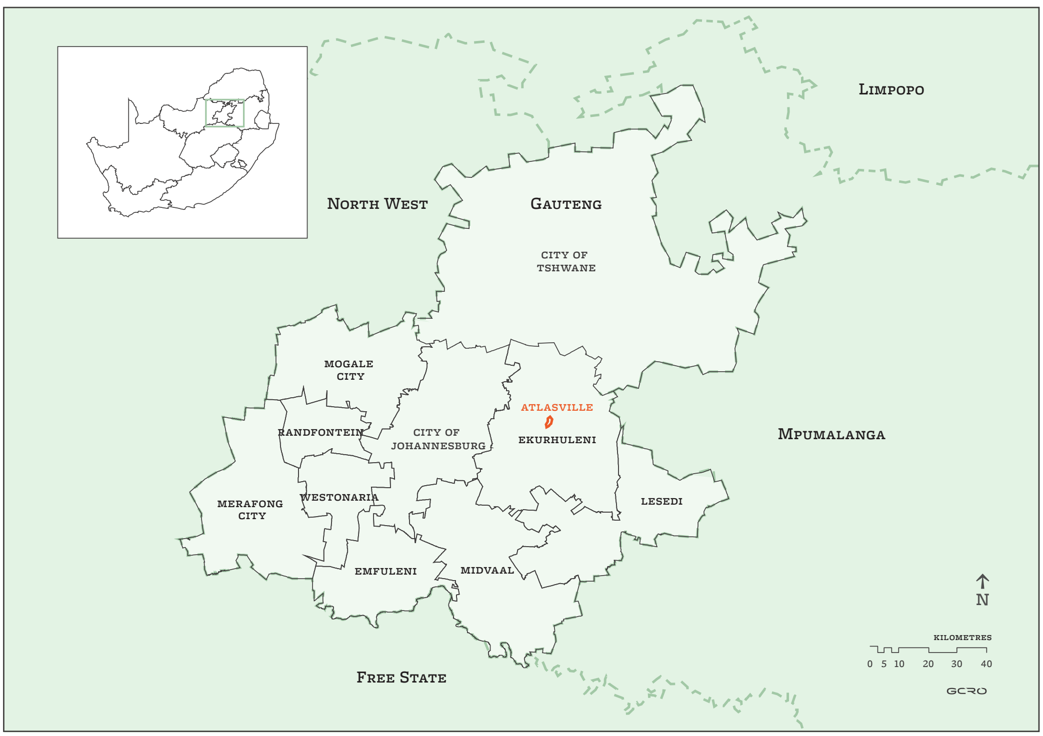
2 Sometimes a municipality only has one option but must still test the costs versus the benefits that will be provided. The decision in such instances may then be whether the scheme is implemented or not.

## Atlasville project background

Atlasville is a suburb in the northern region of the Ekurhuleni Metropolitan Municipality (Figure 5.1). The suburb is approximately 2 km in length and just over 2 $km^2$ in area. A small river, the Atlas Spruit, runs through the length of the suburb. Atlasville is fed by a catchment area of just over 25 $km^2$ (large for an urban context) with a range of land uses, including OR Tambo International Airport, light industry, commercial and residential areas (Figure 5.2). The suburb has experienced intermittent flooding in recent years. The Atlas Spruit flood relief scheme, which is described in this chapter, was designed to alleviate flooding and flood risk through the suburb.

This project required careful study of the complex mix of land uses to ensure that flood responses during storm events were understood and to ensure that the hydraulic capacity of the scheme could be calculated (Fourth Element, 2011; PBA International, 2009). The water bodies and wetlands in the catchment are of particular interest as many already provide important flood control during storm events, by partly absorbing the flooding from the built-up areas. In particular, Blaauwpan and the wetland upstream of Brentwood Park Road provide critical flood control of runoff from the airport and industrial areas which dominate the western half of the catchment (Figure 5.2).

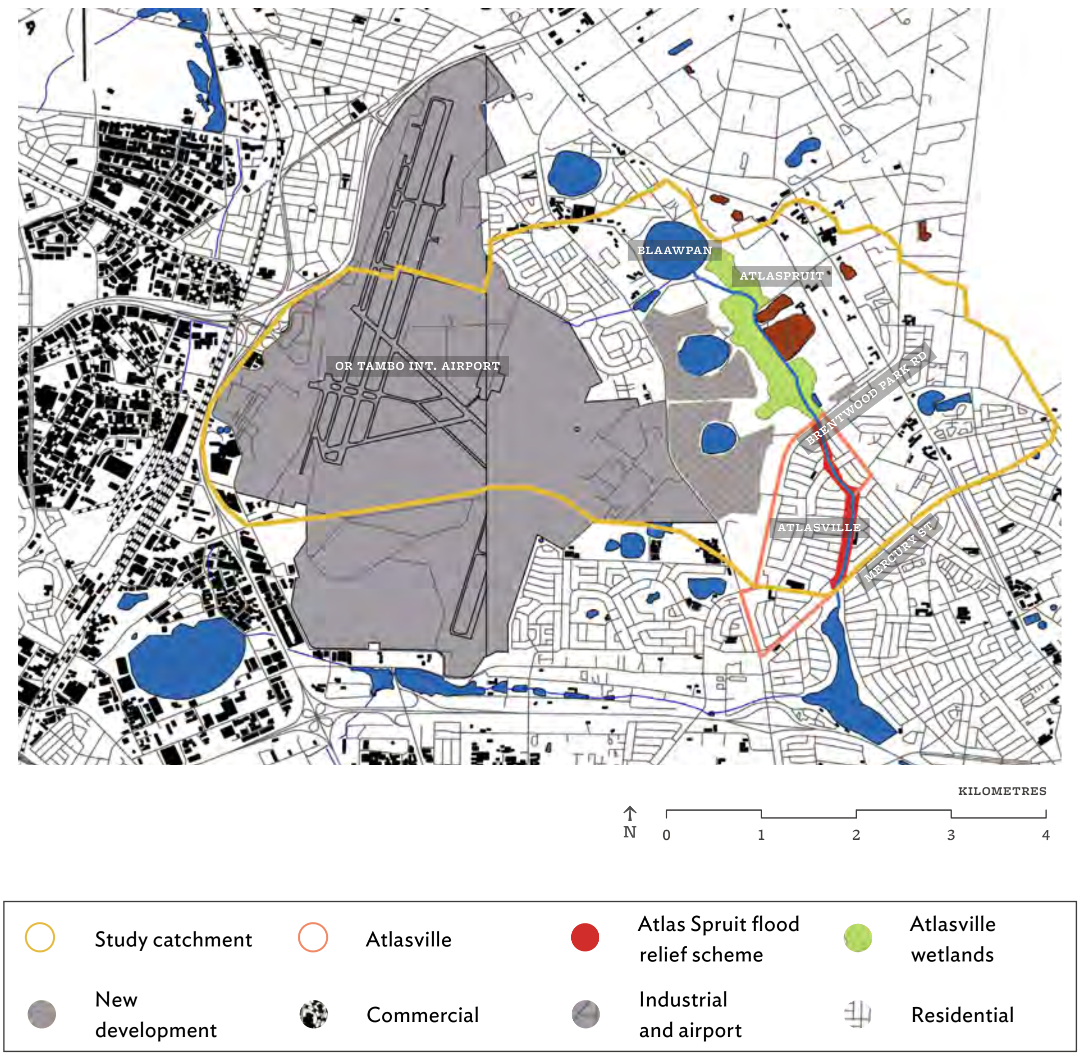
**Figure 5.1:** Location of Atlasville, a suburb in the northern parts of Ekurhuleni Metropolitan Municipality



The stormwater services provided by these wetlands and water bodies are not well defined within the municipality. However, the municipality does acknowledge these features in terms of their biodiversity and recreational value, and they could be considered as green assets on the basis of these ecosystems and amenity services alone. By developing the Atlas Spruit flood relief scheme in line with a GI approach, the scheme forms an important link between the pans and wetland upstream and Homestead Lake downstream. This extends a linear green corridor that has all the fundamentals of GI, that is, a multi-functional network of ecological features that provides a range of services in a similar way to traditional grey infrastructure.

**Figure 5.2:** Atlas Spruit flood relief scheme and associated catchment, showing the main water bodies (in blue)

**SOURCE:** Fourth Element (2011)



*Early township establishment and catchment development*

The Atlasville township developed in the mid-1970s (Figure 5.3). At the time, much of the area was arable land with the exception of the northern half of the suburb which, based on historical photography, appears to be a vlei[3] or wetland. The wetland was drained by excavating a channel through its middle – the Atlas Spruit – and housing was built in the drained areas. However, this left part of the new township below the level of the riverbank (Figure 5.3). To prevent the low-lying areas from being flooded, the new channel would have to have been hydraulically efficient,[4] typically deep and steep-sided, which would have reduced flood risk, but would also have limited the potential for ecological habitat and public amenity. The area immediately alongside the canalised Atlas Spruit remains a park area.

The depth and steepness of the river channel also made it prone to bank collapse and vulnerable to the establishment of pioneer plant species, such as reeds, that eventually dominated the watercourse. The watercourse required seasonal management by either cutting or burning the reeds, and some sediment removal. Maintenance activities stopped in the early 2000s, and the reed growth reduced the hydraulic capacity of the stream.[5] This was one of the reasons behind the flooding that started in 2006 in Atlasville (PBA International, 2009).

Another cause of flooding was the progressive development in the catchment since Atlasville was established (visible in aerial photographs of the area). The area has developed from a primarily agricultural catchment in the early 1970s (Figure 5.3) to the mixed land use seen today (Figure 5.2). In 1995, large parts of the catchment were still agricultural holdings, but there has been substantial development in the catchment in recent years, and in fairly close proximity to the Atlas Spruit. This development has resulted in an increase in impermeable surfaces, which prevent stormwater from infiltrating the ground, resulting in increased stormwater runoff. Figure 5.4 shows areas of new development since 2002. The combined area that has been developed over the past 15 years exceeds 300 ha, which is 12% of the total catchment area. These areas are either upstream of the flood risk area in Atlasville or drain directly into the flood risk area.

*When the Atlasville township was developed, much of the area was arable land, with the exception of the northern half of the suburb, which was a wetland*

3 A vlei is a South African term for a natural area with marshy ground and covered in a shallow layer of water.

4 Hydraulic efficiency relates to the shape and roughness of the river channel. A straight, relatively smooth-sided channel that is both narrow and deep will flow faster and is more hydraulically efficient than a wider, more natural meandering, shallow-bottomed and vegetated channel that will tend to flow more slowly.

5 Hydraulic capacity refers to the volume of water that can fit within the river channel.

**Figure 5.3:** Aerial photograph showing the early township establishment of Atlasville (1976)

**SOURCE:** Fourth Element, with base image from National Geomatics Management Services


**Figure 5.4:** Areas of new development since 2002 (in yellow). Phase 1 of the Atlas spruit flood relief scheme is shown outlined in green.

**SOURCE:** Fourth Element, with base image from Google Earth (2015): 26° 09' 0.46" S and 28° 17'19.51" E

*Flood history*

The incremental development in the catchment increased paved and roofed areas, and resulted in greater volumes of surface water runoff into the canalised Atlas Spruit during rainfall events. In February 2006, after a moderate storm event (5-year), the capacity of the Atlas Spruit channel was exceeded for the first time and properties adjacent to the watercourse were inundated. Subsequent to this 2006 flood event, flooding was recorded almost annually with some residents on constant alert in the summer rainfall season. Two of these events, which occurred within a week of each other in January 2010, caused widespread flooding in the suburb (Figure 5.5) (Fourth Element, 2011).

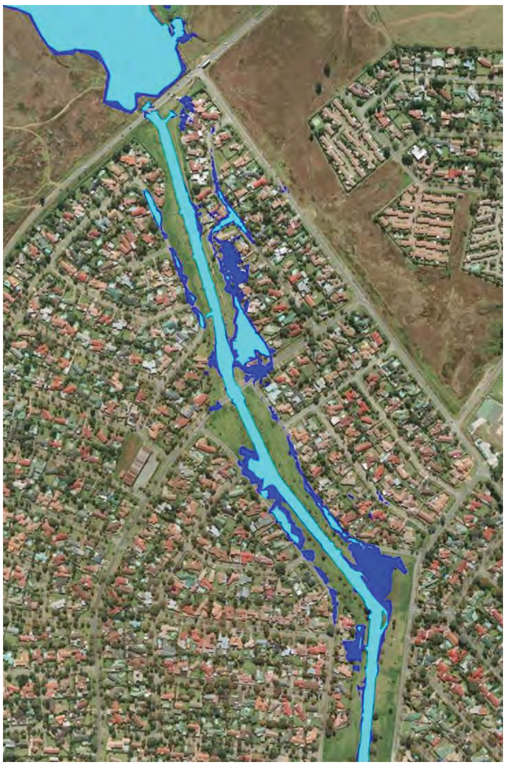
Assessments of these floods show that the flooding was caused by the combined impact of increased stormwater runoff in the catchment and the reduced capacity of the river channel due to reed establishment and siltation (VC Management Services, 2010). Flooding was exacerbated by the low-lying areas of the suburb that saw increased risk of flooding even when the Atlas Spruit had not burst its banks. In these areas, flood waters from the stream backed up the stormwater drains and flooded the low-lying areas (Figure 5.6).

**Figure 5.5:** Flooding in Atlasville in 2010. (A) shows the high water mark well above floor level; (B) shows flooding in Gompou Street (along the spruit); (C) shows flooding within the suburb, possibly Falcon Street (away from the spruit); (D) shows flood levels in the spruit (note flood waters are almost at bank level but reeds still stand upright, increasing flow resistance and increasing flood depth).

**PHOTOGRAPHS** by Vincent Carruthers (A, B and C); Fourth Element (D)

**Figure 5.6:** A flood simulation of one of the January 2010 events. This clearly shows the backwater effect of river water levels pushing flood waters up the storm drains into the low-lying areas.

**SOURCE:** Fourth Element, with base image from the City of Ekurhuleni



The flood events led to increasing anxiety among affected residents, and concerns by others that they would be vulnerable to larger flood events. Residents reported feeling anxious during the summer storm season, and one family had to relocate due to the emotional stress experienced during storm events. Many residents experienced flooding within their houses and some residents reported that with the frequency of the events, their insurance claims against the damage became increasingly difficult to cover.

The community placed pressure on the municipality through lobbying and mobilising their local councillor, and as a result, the Ekurhuleni Metropolitan Municipality undertook to find a solution to the problem. This involved the assessment of a number of alternatives and, with the agreement of the community, a preferred solution was selected. This solution – the Atlas Spruit flood relief scheme – is outlined next.

*The flooding was caused by the combined impact of increased stormwater runoff in the catchment and the reduced capacity of the river channel due to reed establishment and siltation*

## Atlas Spruit flood relief scheme

The Atlas Spruit flood relief scheme was developed based on modelling studies of the catchment and the spruit, conducted by Fourth Element and with input from the City of Ekurhuleni and local residents to ensure the cause of flooding was clearly understood. These models enable comparison between flood responses in different scenarios and in response to various potential interventions. Figure 5.6 provides an example of the modelling simulations that were done using an event in January 2010. These modelling studies were carried out over a number of phases, during which the potential solutions were narrowed until the preferred scheme was identified by the engineers in consultation with the municipality.

The following sections provide details on both the green and grey scheme designs. The green scheme draws from the actual project which was designed and implemented in Atlasville. The CBA undertaken in this chapter necessitated that a conceptual grey infrastructure scheme be developed for comparison with the green scheme. Note, however, that there is a risk in comparing a detailed design of one scheme with a concept design of another because certain details in the concept design may be missed. This, in turn, might have a bearing on the overall cost of the concept scheme. Nevertheless, effort has been made to cover as much as possible in this conceptual grey infrastructure solution and to ensure that the main features of the scheme have been accounted for. It is equally important to not over-design the grey scheme and distort the comparison with the green scheme. As such, it is considered that the grey infrastructure scheme presented in this study provides a realistic comparison with the green scheme that has been constructed in Atlasville.

### Green scheme design

The primary focus of the scheme was flood relief, but, as the design process evolved, attention was given to expanding the services provided by the scheme. These included ecological enhancements and community benefits, thus bringing the project in line with a GI approach. A foundational premise of this approach is that infrastructure assets provide multiple services with an emphasis on a network of healthy ecosystems (Dunsmore, 2016). However, it is not common to register multiple services for municipal assets in Ekurhuleni and this remains one of the institutional obstacles for the roll-out of GI (Dunsmore, 2016). The Atlas Spruit scheme has been registered as an asset in the Ekurhuleni Roads and Stormwater database for its stormwater conveyance and flood relief services. However, the other services that are provided by the scheme are not yet referred to on the asset registry. The scheme's status as an asset is important in ensuring budget is allocated to its maintenance. It is the hope that – with the active participation of the departments interested in the performance of the scheme, its benefits to the surrounding communities and with the multiple ecosystem services that the scheme provides – this green asset could become a pilot study for the inclusion of GI with multiple services as a municipal asset, with at least equivalent status to traditional grey assets.

In this project, the detailed modelling of the scheme has been particularly important. Any error in the design of this GI solution would affect all of the associated services. For example, incorrectly estimating flow patterns and velocity may destabilise the ecological habitat and could even present a hazard for the park users. Similarly, incorrect specification of instream vegetation could seriously compromise the hydraulic function of the stream with the potential for increased flooding. The latter was a particular concern for the project, as the vegetation in the channel affects both the construction and long-term maintenance requirements of the drainage scheme.

The Atlas Spruit scheme has therefore raised awareness that providing multiple services through GI may require more comprehensive design processes to ensure that all of the intended services do not fail, or do not have additional capital cost (or maintenance) implications. This, in turn, may affect the cost–benefit ratio of a scheme if one or more of the services is at risk of failure.

During the design process, the scheme was split into two phases for budgetary reasons. Phase 1 focused on the upper half of the scheme that was more prone to flooding, and the lower half of the scheme was covered in Phase 2 (Figure 5.7).

There are three main services of the scheme, each of which is outlined in the sections below. When setting the multiple services of GI in stormwater management, it is important that a primary service is identified. This service should then take priority over all other services in any design and maintenance specification for the scheme. In the Atlas Spruit scheme, flood relief was the primary service, and recreational amenity and ecological value were secondary services.

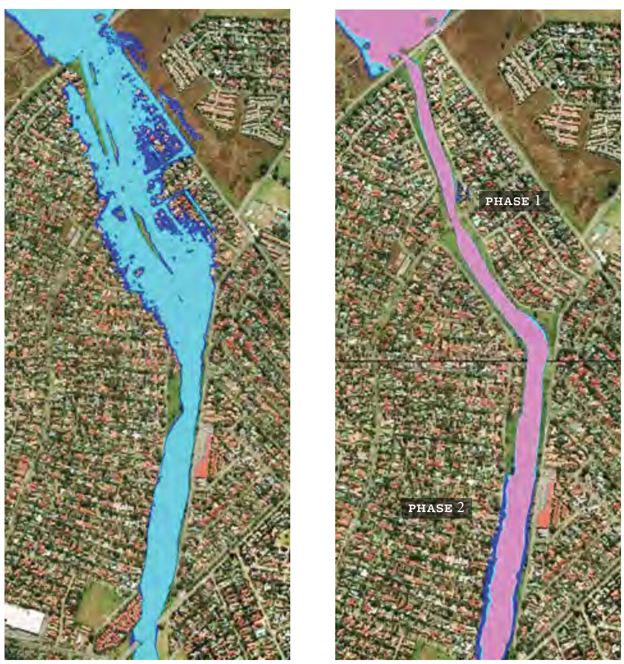
*Flood capacity (primary service)*

It was estimated that with the implementation of Phase 1, 100-year flood relief would be attained in the upper reaches of the scheme (i.e. through the zone where Phase 1 would be constructed) and 50-year flood relief for the Phase 2 zone. Figure 5.7 gives an indication of the flood relief achieved with the implementation of Phase 1. Greater hydraulic capacity was achieved through a combination of widening the channel, deepening it by removing the silt build-up, and improving the hydraulic efficiency in the main part of the channel. Changing the hydraulic efficiency (reducing the roughness of the channel), which entailed the removal of the reeds which have a particularly high flow resistance, proved the most controversial part of the project. Some residents were concerned about removing the reeds and disturbing the ecological habitats associated with wetlands. However, wetlands are more than just reeds, and the design was able to consider alternative plant species for the final scheme to enhance the ecological functioning of the channel.

The widening of the channel was also questioned by the community over concern of loss of park space along the spruit. Therefore, while the hydraulic capacity of the system remained the primary design criteria, the specification of the scheme sought to achieve a balance between the flood relief objective and the other services of ecology and amenity.

**Figure 5.7:** (A) Pre-development and (B) post-development 50- and 100-year flood lines. In the post-development figure, the 20-year flood line was included in the design drawings. (B) also indicates the location of the different phases of the project.

**SOURCE:** Fourth Element, with base image from the City of Ekurhuleni




(A) Pre-scheme flood lines:
- 50-year (light blue)
- 100-year (dark blue)

(B) Post-scheme flood lines:
- 20-year (purple)
- 50-year (light blue) and
- 100-year (dark blue)

*Recreation amenity (secondary service)*

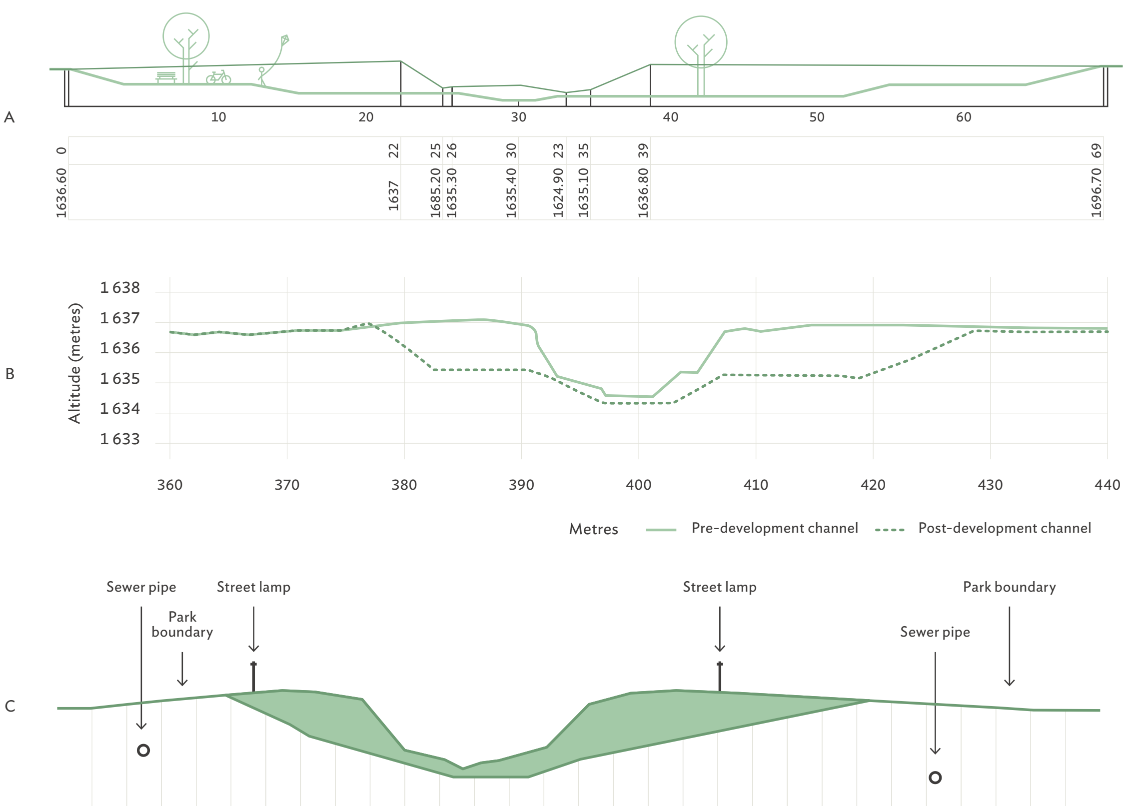
An important secondary service of the scheme was to preserve and, where possible, enhance the public park and recreation facilities provided by the original park. The new scheme needed to be able to use the entire width of the park area, and a balance needed to be achieved between creating hydraulic capacity and recreational space. Although a deep channel may be more hydraulically efficient, it is not safe to play alongside.

Figure 5.8 summarises the development of the preferred channel section. A landscape architect played a key role in this process. In Phase 1, excavated slopes of the floodplain at the edge of the park were constrained to achieve a gentle and more natural landscape. This ensured comfortable angles for walking and recreation, and ultimately enabled easier access to the stream. In narrower portions of the park, this was not always achievable due to space constraints, and therefore the slopes are steeper in these areas.

In Phase 2, the scheme was designed to accommodate the shallower channel and the presence of many mature trees in the park that were to be retained. A number of shallow swales[6] were introduced to create more conveyance and helped preserve much of the original recreational park area.

**Figure 5.8:** Incorporating landscape and park aspects into the design. Cross-sections of: (A) early park concept; (B) sizing for hydraulic conveyance, but using a stepped channel for ease of recreation access; (C) final profile with gentle slopes enabling direct access to the stream edge.

**SOURCE:** Fourth Element




6 A swale is a shallow vegetated channel designed to lead runoff towards a storage area or watercourse.

*Ecological value (secondary service)*

Ecological enhancement was also a secondary service of the scheme, though this was introduced relatively late in the design process. In the same way that designing for public amenity and access requires the professional input of a landscape architect, this project revealed that designing an enhanced ecological habitat requires the input of an experienced freshwater ecologist. Unfortunately, an ecologist was not included on the team for the Atlas Spruit flood relief scheme and, while some habitat improvements have been demonstrated in Phase 1, the full potential of habitat enhancement was not achieved and is a lost opportunity as a result.

Despite the lack of ecological expertise, the outcome of Phase 1 demonstrates that just the use of vegetated solutions (green solutions) in the hydraulic design of the scheme can achieve significant ecological benefits. The intention of the Atlas Spruit scheme was to minimise the use of grey infrastructure solutions such as concrete-lined channels, concrete weirs, etc. (grey solutions) and maximise the vegetation cover of the scheme. While the focus was still hydraulic capacity, channel stability and flood management, the use of GI automatically increased the opportunity for ecological enhancement.

The main components of this included the revegetation of the entire length of the main channel in Phase 1, the removal of reeds (though this was primarily for hydraulic reasons), the use of indigenous plants only (this meant the removal of kikuyu lawn grass and seeding of natural grasses), and the introduction of reed beds and riffle weirs into the channel design.

Figure 5.9 provides an example of the pre- and post-Phase 1 condition of the Atlas Spruit, showing reed dominance before the scheme was built (left) and a more open and diverse habitat (right) two years after Phase 1 was completed.

**Figure 5.9:** Atlas Spruit habitat in Phase 1. The photo on the left, taken in 2009, shows the main channel dominated by reed growth (*Typha sp.* and *Phragmites sp.*), and that on the right, taken March 2015 after construction, shows greater diversity with a mix of open water and a range of vegetation types.

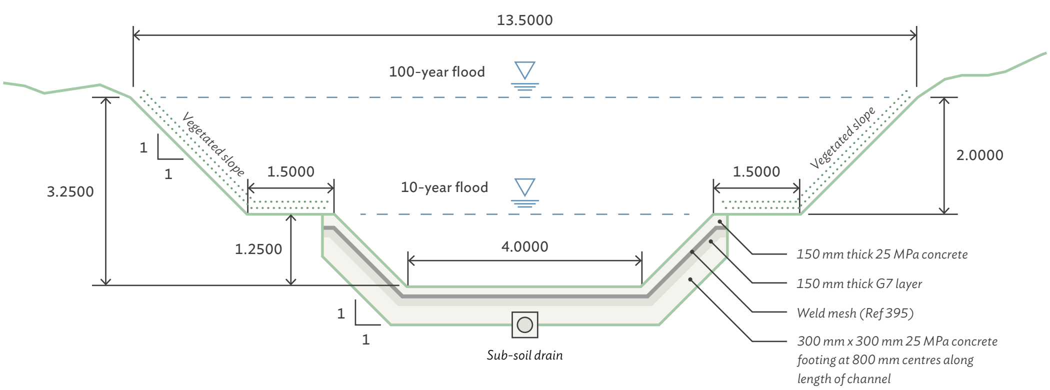
**PHOTOGRAPHS** by Fourth Element

## Grey infrastructure scheme design

In keeping with the approach of the green scheme, the main objective of the grey scheme was to alleviate flooding. The grey scheme was designed for the same flood capacity (100-year) as that achieved with the green scheme. It would be possible for the grey scheme to comprise a simple concrete channel with the capacity to contain the entire 100-year flood, but a more likely scenario is for a scheme where the concrete channel is designed to contain the more frequent, smaller flood events, and that the overall capacity of the system, including vegetated floodplains, would contain the 100-year flood. The grey scheme considered in this assessment comprises a compound trapezoidal channel consisting of two stages. The first stage would be concrete-lined (designed for the 10-year flood) and the second stage, unlined and vegetated with short grass. The total capacity of the channel is designed for the 100-year flood. A sketch of a cross-section of the scheme is given in Figure 5.10.

**Figure 5.10:** Cross-section detail of proposed grey infrastructure concrete-lined channel

**SOURCE:** Fourth Element




*In keeping with the green scheme, the main objective of the grey scheme was to alleviate flooding*

*Concept design*

The alignment of the channel was determined by the centre line along the existing river corridor. The footprint of the channel was minimised to retain as much of the recreational park area adjacent to the watercourse as possible. The differences in excavation between the green and grey schemes are shown in the cross-section profiles of Figure 5.11 and Figure 5.12. The green shading in these figures shows the amount of excavation proposed. It is clear that less excavation is required with the grey scheme, which results in a narrower but deeper conveyance channel.

**Figure 5.11:** Cross-section profile showing earthworks excavation for the GI scheme. Green shading indicates the extent of excavation.

**SOURCE:** Fourth Element

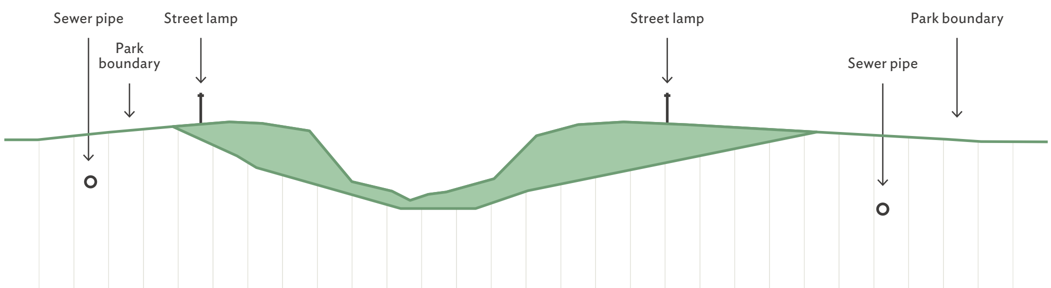
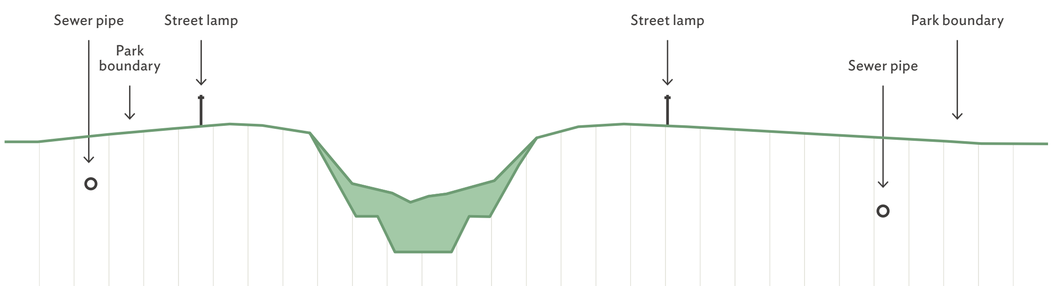



**Figure 5.12:** Cross-section profile showing earthworks excavation for the grey infrastructure solution. Green shading indicates the extent of excavation.

**SOURCE:** Fourth Element



## Green versus grey scheme: Costs and benefits

For the purposes of this study, the CBA approach has been adapted to compare a GI scheme with an equivalent grey infrastructure scheme. The comparison is therefore green versus grey, with the intention of assessing whether a green scheme can be defended as a better option to a grey scheme. Both costs and benefits of each option are analysed, although in some cases the analysis is qualitative only. Where possible, a cost–benefit ratio was calculated. The scope of the analysis is based on the ecosystem services that were ultimately included in the design of the Atlas Spruit flood relief scheme. The main elements of the analysis include:

- Capital cost of the GI solution, derived from the actual cost of the construction of the scheme;
- Capital cost of an equivalent grey infrastructure solution, developed to concept design stage;
- Anticipated operations and maintenance requirements for each scheme;
- An assessment of the social benefits through a survey of community perceptions of the GI scheme, its benefits and any dis-benefits (qualitative assessment);
- An evaluation of the ecological and habitat performance of the GI scheme (qualitative assessment); and
- An investigation of property values in the suburb, and more specifically along the Atlas Spruit, before and after the flood relief scheme.

The CBA, which includes the various components listed above, is summarised and based on the combination of individual components.

### Cost comparison

The costs of the green and grey schemes include capital and maintenance costs. The capital costs are related to the cost of works required for the construction of the respective schemes. The capital cost comparison includes rand value comparisons. The maintenance costs for the respective schemes have been assessed on a more qualitative basis, and thus the comparison between the two schemes is qualitative.

#### *Comparison of cost of works*

Typically, a bill of quantities (BoQ) is generated for a scheme at the end of detailed design. It lists the main components and construction activities required to build the scheme, allocating costs to each component. The BoQ is used as a basis for estimating the cost of constructing the scheme. In this case, the actual cost of the scheme is presented for the GI solution and an estimate has been prepared for the grey scheme. Summaries of each are presented in Table 5.2. These include both Phase 1 and Phase 2, adjusted for prices as at April 2015.

Table 5.2 compares the costs of the green and grey schemes. The capital cost of the grey scheme is around 5% more than Atlasville's green scheme. However, this margin is small and a fairer comparison might be rather that the green scheme is, at worst, equivalent to a grey infrastructure scheme with the same primary service capability (i.e. the safe conveyance of a 100-year flood).

For the green scheme, the earthworks and landscaping are clearly the major cost items, and these are expected to be central to most GI projects associated with drainage. Erosion protection may also be a regular feature of GI BoQs, especially in urban environments where high-energy flash flooding is more likely. Other items will be more site and project specific.

The grey scheme still shows significant earthworks costs, but, as expected, the concrete item accounts for the bulk of the cost. One of the main uncertainties is the landscaping component. The budget shown assumes basic rehabilitation would be done with a grey infrastructure scheme, without removing exotic species or introducing ecological features, or even developing a varied landscape. It also assumes that there would not have been a wider profiling of the park with additional earthworks. In reality, either the client or the community may add to the scope of construction or landscaping, or the environmental authorisation may add conditions that affect the construction works. However, the assumption was made that the grey scheme is likely to have simple environmental requirements as it mainly requires concrete construction rather than developing vegetated systems along the spruit.

**Table 5.2:** Cost breakdown for the green and grey schemes for the Atlasville flood relief scheme (April 2015 costs)

**SOURCE:** The cost estimates have been drawn from a combination of experience in the sector, costs from Phases 1 and 2 of the scheme, and generic costing of materials and construction rates (updated to April 2015)

| Section* | Description | Cost of the green scheme | Cost of the grey scheme |
|---|---|---|---|
| 1200 | General requirements and provisions | R503 452 | R503 452 |
| 1500 | Accommodation of traffic | R395 833 | R395 833 |
| 1600 | Overhaul | R505 179 | R99 000 |
| 1700 | Clearing and grubbing | R1 719 360 | R453 634 |
| 1800 | Dayworks | R634 370 | R992 423 |
| 2100 | Drains | R377 055 | R529 687 |
| 2200 | Prefabricated culverts | R1 396 605 | R1 396 605 |
| 2300 | Concrete kerbing, concrete channelling, chutes and downpipes, and concrete linings for open drains | R0 | R13 356 430 |
| 3300 | Mass earthworks | R15 804 492 | R7 075 625 |
| 3600 | Crushed stone base | R0 | R2 702 146 |
| 5100 | Pitching, stone work and protection against erosion | R15 250 | R15 250 |
| 5200 | Gabions and pitching | R551 473 | R275 737 |
| | **Sub-total** | **R21 903 070** | **R27 795 821** |
| | Variation orders (erosion control) | R 569 740 | |
| | Landscaping | R 4 320 200 | R 200 000 |
| | **Grand total** | **R 26 793 009** | **R 27 995 821** |

*The codes in this column are those used by the Ekurhuleni Metropolitan Municipality: Roads and Stormwater.

**Table 5.3:** Assessment of maintenance requirements for the green and grey schemes

| Green scheme maintenance: *Frequency & cost* | Grey scheme maintenance: *Frequency & cost* |
|---|---|
| **Grass-cutting (floodplain): Residents requested that the floodplains were to be cut as lawns.** | |
| An alternative to test with the community is to allow the *cynodon spp.* grass to grow naturally with minimal cutting. This will still require some maintenance (e.g. cutting once a year before winter), but will enhance the ecological diversity of the river corridor.<br><br>*Once or twice in summer, at moderate cost.* | Same as green scheme. Mechanical mowing once or twice seasonally (wet season).<br><br>*Once or twice in summer, at moderate cost.* |
| **Reeds and vegetation (in-channel): Seeds of *typha spp.* and *phragmites spp.* in particular will continue to be released from above Brentwood Park Rd, and will establish in sediment and disturbed areas.** | |
| The desired state is a stable, naturally regenerating plant mix within the channel. Reed seeds will establish in areas of disturbance or 'open water' if velocities are low enough.<br><br>*In years of early establishment, reed removal by herbicide will need to be done frequently (e.g. annually), but as the desired vegetation is established, it is hoped this will drop (e.g. every 3–5 years). The situation needs to be monitored for full understanding of how this will develop. Manual methods are best, at low cost.* | Linked to sediment build-up, any vegetation establishment in the concrete section of the channel should be removed.<br><br>*In line with sediment removal, and undertaken at the same time. Mechanical or manual methods will apply, at moderate cost.* |
| **Sediment deposition: Sediment build-up was one of the causes of flooding. Sediment loads are more likely from the local catchment than upstream due to trap efficiency of the upstream wetland. However, local catchments are now more developed, presumably resulting in lower sediment load. Future loads are unknown, but could be decreasing.** | |
| Sediment will collect in the channel, particularly under the slower velocities of a vegetated channel. Build-up may be less noticeable, and key point monitoring may be required. The channel has been designed with spare capacity, but the rate of build-up is unknown.<br>Reed establishment should be less likely if the vegetation mix is established and stable, but reeds will still establish in disturbed areas.<br><br>*Infrequent maintenance (e.g. every 10–15 years), at high cost, including in-channel plant rehabilitation. Mechanical methods may be best. Removal of erosion protection (MacMat®) may occur but need not be replaced if carefully planned and treatment is in strips across the channel.* | Sediment will no doubt collect in the concrete channel and, if not cleaned, will attract vegetation growth. In extreme conditions, reeds may establish and become a hydraulic risk.<br>Monitoring will be relatively easy, and cleaning will be in line with Roads and Stormwater's regular maintenance activities.<br><br>*Frequent maintenance (e.g. every 2–5 years). Mechanical or manual methods will apply, at moderate cost.* |

| Erosion control and bank stability | |
|---|---|
| Slower flood velocities and flatter bank slopes will result in lower erosive shear stress on the banks and bed of the river. If vegetation is correctly maintained, the risk of scouring and erosion should be minimal. | Flow velocities in the grey scheme will be higher, offering greater potential for scouring and erosion. However, this should only occur above the 10-year event when flood flows enter the grassed second stage of the channel. |
| *Very infrequent. Costs should be minimal if vegetation cover is correctly designed and maintained. Work will include soil replacement, provision of protection if necessary (e.g. gabions, riprap, etc.) and revegetation.* | *Very infrequent. Costs should be small to moderate if vegetation cover is correctly designed and maintained. Work will include soil replacement, replacement of the concrete lining or provision of protection if necessary (e.g. gabions, riprap, etc.) and revegetation.* |

### *Anticipated operational and maintenance requirements*

A recent assessment of the roll-out of GI in Ekurhuleni Metropolitan Municipality showed that although multiple departmental stakeholders have interest in projects such as the Atlas Spruit flood relief scheme, the interdepartmental policy and responsibilities on maintenance need to be resolved (Dunsmore, 2016). The kind of maintenance required by a GI project are relatively unfamiliar to the maintenance teams. The comparison of the maintenance requirements of grey and GI solutions is therefore a qualitative one at this stage. It is reliant on anticipated activities in the context of the Atlas Spruit and its catchment as they are understood at the time of writing.

In both the grey and green schemes, the main maintenance duties are expected to focus on monitoring and management of sediment and reeds. Manual labour methods are anticipated for each due to the desire of the municipality to utilise manual labour methods where possible. The different aspects of maintenance are presented in Table 5.3.

The grey scheme is likely to require more frequent maintenance, albeit at a relatively low to moderate cost. The additional benefit in the short term is that the kind of maintenance of the grey scheme is familiar to the Roads and Stormwater Department. Maintenance of the green scheme should be minimal if vegetation establishment is successful and stable. The key to ensuring this is the management of reed encroachment in the short term. If successful, this should settle to a manageable herbicide treatment every two years or so. However, this form of maintenance is not familiar to the Roads and Stormwater Department and will need the cooperation of the Parks Department.

Sediment is a threat to both schemes in that it will build up in either scheme if the Atlas Spruit continues to carry significant sediment loads. Catchment controls should be planned for the long-term management of sediment, but this may not materialise. The grey scheme will require regular maintenance if sediment loads are significant, while the green scheme will likely be more tolerant of sediment build-up. However, in the long term, the green scheme will need to be dredged of sediment if build-up threatens flood conveyance capacity, which is likely to be an expensive process.

## Ecological habitat comparison

Ecological habitat enhancement was one of the secondary aims of the Atlas Spruit flood relief scheme, although there was no specialist ecological input in the design phase of the project. This was identified as a notable gap in the design process when this post construction review was undertaken. An assessment of the new habitat was conducted two years after the completion of Phase 1 construction and was compared to the pre-scheme condition. The assessment focused on both in-stream and riparian habitats.[7]

The post-construction assessment was done in winter, which is not ideal as many plants die back during the dry winter season. The structure of the stream was assessed, focusing on an analysis of vegetation diversity and the structure of both in-stream and riparian zones, and observation of fauna activity.[8] The same information for the pre-scheme conditions was gained through photo records, Google Earth historical imagery and the wetland delineation studies undertaken for the scheme's environmental impact assessment (EIA) (VC Management Services, 2007, 2010). Habitat units were defined as shown in Table 5.4. These habitat units are mapped for Phase 1 as shown in Figure 5.13.

The pre-scheme ecological condition was one of dense reed growth, persisting almost entirely throughout the length of Phase 1 of the Atlas Spruit project. Such habitat favours low bird species richness and was thus considered low value habitat. Post construction, a larger mix of species was introduced and, while reeds were still present throughout Phase 1, the proportional representation of reeds was lower with a more sparse distribution and a good diversity of height. The reed distribution could thus be considered as either medium value or even high value in instances where the reeds were present in a mosaic of plants of different species and heights.

There also appears to be a higher bird species richness in the completed Phase 1 section than in the pre-scheme condition. The semi-dense stands of reeds present in the new scheme host bird species with a preference for this habitat (e.g. *Cisticola sp.*) compared to reports of a dominance of two species, Widowbirds and Red Bishops, in the pre-scheme condition. Neither of these was detected during the post-scheme survey. These species usually prefer tall reeds and grass cover and are likely to return as the vegetation establishes over time. Only two of the species that were listed in the pre-scheme EIA were identified during the post-scheme survey, the African Snipe and Greyheaded Gull. However, new species included the African Darter and African Spoonbill, both carnivorous birds, with the darter feeding mainly on fish, though both will eat amphibians and invertebrates. This is indicative of improved faunal species abundance in the stream. Overall, there appears to be a turnover of bird species, with many of the originally listed species no longer present and the emergence of new species. These results might be attributed to assessment in different periods. Although the results appear positive, it would be helpful to carry out a survey in summer to confirm these initial findings and enhance the comparability with the pre-scheme assessment.

*The arrival of two carnivorous bird species is indicative of improved faunal species abundance in the stream*

7 The riparian zone refers to the habitat within the narrow strip of land along the stream above the normal water line.

8 The structure of the stream refers to the physical makeup of the watercourse and includes such aspects as bed material, distribution of the type and height of vegetation, and the presence of open water sections.

Overall, there has been a positive change between the pre- and post-scheme habitats, with the majority of the area shifting from a low quality to either a medium or high quality habitat. The post-scheme also has a much larger area of open water, which can be beneficial for aquatic ecosystems. However, assessing whether this has indeed been beneficial requires a summer season aquatic survey.

The pre-scheme surveys reported the value of the wetland to be 'good' mainly due to the presence of the reeds, but it also noted very low dissolved oxygen conditions in the stream. This would limit the habitat potential for fish, tadpoles and certain invertebrates. In fact, the pre-scheme surveys recorded only one frog species in the stream, but as many as five species were recorded in the upstream wetland, north of Brentwood Park Road. The cause of the low dissolved oxygen measurements is not certain, but it might have been caused by dense reeds that prevent sunlight from reaching the water. This would, in turn, limit photosynthesis by aquatic algae and reduce the generation of oxygen within the aquatic system. Eventually, microbes that exert an oxygen demand replace the algae, further reducing dissolved oxygen in the water (Hunt & Christiansen, 2000). So, while reeds are obvious markers for wetlands, they do not necessarily indicate healthy aquatic conditions.

The assessment suggests that the Atlas Spruit scheme has improved the ecological habitat in the spruit. The blanket dominance of the pre-scheme reeds has been replaced by structural diversity and a mix of vegetation and open water sections. In addition, the presence of a higher bird species richness is a positive outcome. The higher reed species richness noted in the post-scheme assessment is a significant improvement on what appeared to be a condition of moribund reeds which impeded habitat development in the pre-scheme habitat. However, without monitoring and maintenance, the reed species richness might reduce over time if the newly introduced reeds do not establish adequately.

In this review of the post-construction state, the ecologist noted that more could have been done to develop the ecological potential of the system. Interventions that could have been developed include: using variable bank shapes; the presence of shallows and beach areas; the introduction of rocks; and the expansion of the riffle areas. These would still need testing for hydraulic capacity and channel stability, but the opportunity appears to be there for some of these to be successful in future projects.

Photograph by Christina Culwick

**Table 5.4:** Range of habitat values assigned to Atlas Spruit Phase 1 with definitions

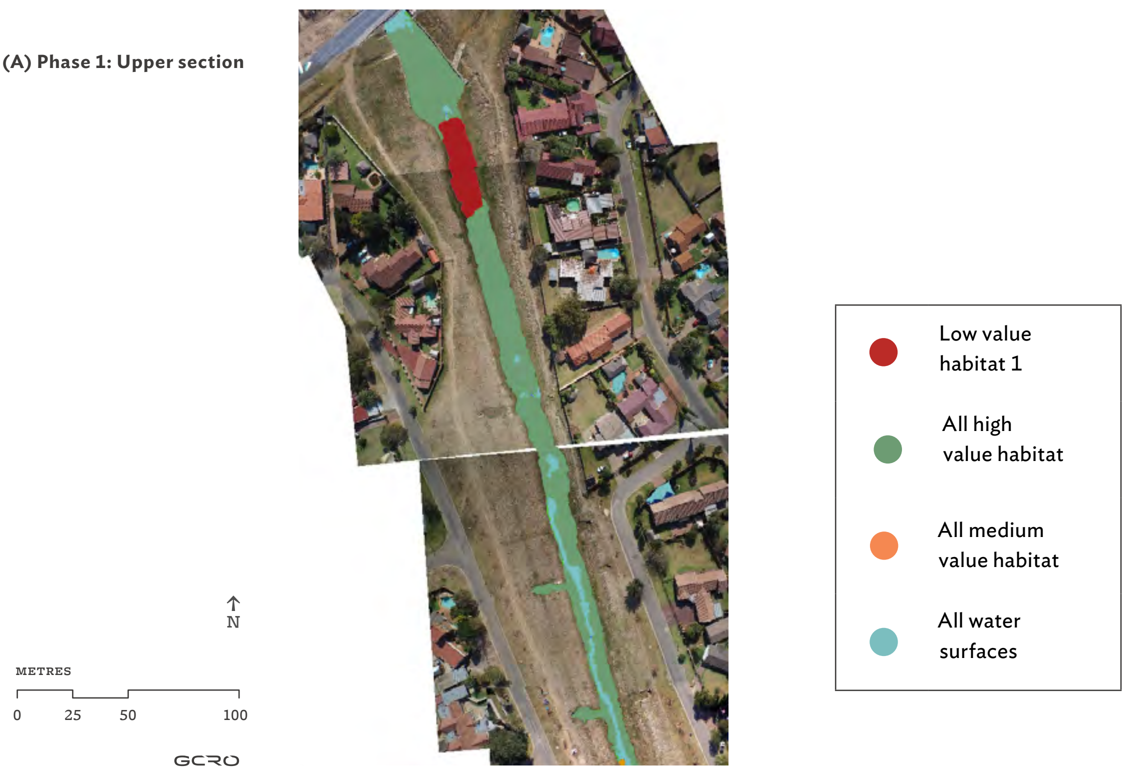
**SOURCE:** Adapted from the approach developed by Noss (1990)

| Habitat values | Definition |
|---|---|
| High value habitat | High species richness, mix of structural components (plants of differing heights) |
| Medium value habitat | Low species richness and intermediate/high structural diversity; or intermediate/high species richness and low structural diversity |
| Low value habitat | Low species richness and low structural diversity |
| Open water | All open water areas |
| Riffle/Cobble | Gabion riffles introduced in the design |

**Figure 5.13:** Atlas Spruit Phase 1 habitat value analysis (July, 2015)

**SOURCE:** Fourth Element

**(A) Phase 1: Upper section**



**(B) Phase 1: Middle section**


- All high value habitat
- All medium value habitat
- All water surfaces
- Riffle/Cobble
- *Phragmites australis* beds

**(C) Phase 1: Lower section**


- All high value habitat
- All medium value habitat
- All water surfaces
- Riffle/Cobble

Photograph by Christina Culwick

## Community and municipality feedback

The Atlas Spruit flood relief scheme's project team interacted with both the municipality and members of the community during the construction and rehabilitation stages of Phase 1 of the project. However, these interactions did not include a review of the scheme as a whole. In this study, key departments within the municipality and the Atlasville community at large were formally approached to comment on the scheme.

### *Community survey*

A questionnaire and an information brochure on the project were circulated amongst the Atlasville residents. The questionnaire was designed to attain an understanding of the public perception of the project in terms of the impact that the project has had on flood relief, property value, status of insurance, ecology and recreation. The community members that were contacted to participate in this study were identified from two databases:

- The Public Participation Database for the EIA phase of the project; and
- Atlasville Project Complainants Database received from the local ward councillor.

Approximately 60 residents were contacted to complete the questionnaire, with 17 respondents returning completed questionnaires (28%). While the results are not statistically significant, they provide individual accounts of the project that help develop an indication of how the scheme is perceived. A summary of the survey is provided below.

Nine of the respondents (~50%) had been flooded previously and none of the respondents have experienced any flooding since the implementation of Phase 1 of the project. Many concluded that property prices and insurances (instalments and monthly premiums) were adversely affected by the flood risk. Properties in the floodplain have been difficult to sell as a result. However, the majority of the residents did not know whether the implementation of the project has influenced property values or insurance.

Although it may still be too early to tell, all respondents expected that the scheme has the potential to increase property values in the future. Just under half of the respondents (40%) were unaware that this is a GI project, but almost 90% of respondents displayed a preference for the green scheme over the more typical concrete-lined channel grey scheme.

Some indication of the cost of damage was provided, but the sample is too small to draw any definitive conclusions of flood damage per event. Values for property damage excluding the main house ranged from R5 000 to over R80 000 (gate motors, pool motors, sheds, walls, etc.) while in-house flood damage costs were well above R300 000 (house structure, appliances and furnishings). One respondent reported cumulative damage costs from 2006 to 2010 at over R2 million. This is well above the average house value (~R1.02 million) for Atlasville in 2010 (see the section on property price analysis).

Just over 70% of respondents felt that the changes to the park along the spruit were positive and that it looked better since the completion of Phase 1. Some noted an increase in visitors to the park, but one indicated she/he had stopped coming to the spruit. Some 70% of the residents saw an improvement in the plant and animal life in the spruit, with many making particular reference to an improvement in the bird life. It is noteworthy that half of respondents were residents who do not live immediately adjacent to the spruit. This implies that the river corridor is seen as an amenity asset by the community at large, and is not just a benefit to those who live along the spruit. Reasons for visiting the river corridor included health and recreation, dog-walking and bird-watching.

In general, there appears to be a positive response to Phase 1 of the scheme. However, some respondents expressed reservations. While the majority of respondents considered the condition of the spruit to be better than before Phase 1 and that the changes had been positive, there was a number of respondents (approximately 30%) who either did not express an opinion or who felt the condition of the park was worse. Their displeasure may be linked to their experience of the construction phase, but comments also referred to unnecessary cost and incorrect evaluation of the causes of flooding. None of these respondents was previously affected by flooding and therefore may not have been as intimately involved in the consultation events during the feasibility studies and detailed designs when many of these issues were discussed. Even though the sample of respondents is small, the proportion of dissatisfied or ambivalent respondents (30%) warrants further investigation.

The construction of Phase 1 was clearly a concern for most respondents and almost all showed displeasure in the manner that it was managed. Their displeasure was attributed to delays in completion, lack of communication on progress, damages to roads and pavements during construction, and the final landscaped product. Some respondents (approximately 20%) were also angry at the topsoil preparation and grassing of the park spaces along the spruit. The prepared ground was uneven, with stones and large clumps of ground, and there has been a call for 'park' grasses (e.g. kikuyu) rather than 'wild' grasses. These respondents considered the park ground uncomfortable to walk on and unsuitable for children to play on. The municipality has acknowledged there were problems with the construction of Phase 1, and many of these issues have been resolved for Phase 2. However, the concerns also point to the potential conflict that may occur between two or more of the services of a GI scheme. The call for 'park' quality landscaping (typically using exotic grasses and limited ecological diversity) is partly in conflict with ecological enhancement. Perhaps more consultation could have been done during the concept design stage to achieve the best balance between the public amenity and ecology services of the scheme. What should remain paramount, however, is the primary service, which is the flood relief performance of the scheme.

*Ekurhuleni Metropolitan Municipality comment*

Three departments with a particular interest in the project were consulted during the study. The Roads and Stormwater Department: Northern is the custodian of the project, responsible for its development, implementation and performance. The Strategic Planning Department has metro-wide responsibility for sustainable development policy and strategic planning, and they have been following the project since its feasibility stage. Their interest in the project is more about its use as a case study for developing strategic environmental policies in the municipality. In addition, a meeting was held with the Parks Department, who are now active in maintaining the park area around the spruit. In terms of GI management, these are seen to be the three main municipal stakeholders of the scheme, and would have interest in one or more of the services of the scheme. Under the current municipal structures which are centred on the requirements of grey infrastructure assets, Roads and Stormwater is the owner of the Atlas Spruit scheme (the asset), Strategic Planning is an interested observer and Parks has the maintenance responsibilities thrust upon it because the asset lies within their own asset (the park land and floodplain in the river corridor).

The meetings with the Roads and Stormwater and Strategic Planning departments followed interviews that were conducted with both departments a year prior relating to the roll-out of GI projects within the municipality (Dunsmore, 2016). The interviews in 2014 showed an awareness of sustainable drainage and its early introduction into projects, but that GI was a relatively new concept. These interviews also highlighted institutional limitations in being able to mainstream GI projects. In 2015, it was evident that progress was being made at a departmental level, although institutional structures were still an impediment to this approach. Strategic Planning was then two years old and was incorporating GI into policies and plans as part of the municipality's sustainability and climate change adaptation strategies. Ongoing efforts focus on translating these policies for implementing departments. In parallel, Roads and Stormwater has actively promoted sustainable drainage and GI in projects, and tries to work within the present supply chain procedures to implement these approaches. However, these departments are working in isolation and the current supply chain processes do not accommodate many of the requirements of GI projects.

A key issue that was raised is the definition of GI projects in terms of operational and capital expenditure. There is a bias toward capital expenditure compared to operational expenditure, where the National Treasury acknowledges municipalities for performance in spending capital expenditure on new infrastructure projects while operational and maintenance budgets are not considered at the same level in performance evaluations. At present, most sustainable drainage and GI projects tend to fall in the maintenance category. Exceptions, such as the Atlas Spruit scheme, are where directives for implementation support projects. The Atlas Spruit project was a high priority flood relief scheme. Sustainable drainage or GI was never part of the project definition or the objective of the scheme. For this reason, the Roads and Stormwater Department is largely introducing these components on their own initiative, but most of the projects remain within operational expenditure and will suffer budget limitations.

The meeting with the Parks Department highlighted their lack of involvement in the project, which was an impediment to the project as a result. The separation of responsibilities between the Roads and Stormwater and Parks departments in maintaining projects such as the Atlas Spruit flood relief scheme is an ongoing concern (Dunsmore, 2016). Parks is responsible for maintaining the park areas above the waterline of the spruit and Roads and Stormwater is responsible for the in-channel maintenance, even though Parks is more competent with the type of in-channel maintenance required. However, Parks has been presented with the outcome of Phase 1 of the scheme and is unsure about how best to maintain the park areas. Should they be treated as a natural grassland system, or should they be mown as a lawn on a regular basis as other public open spaces are typically managed? Instruction on this has since come from the residents, and not the Roads and Stormwater Department or the project team.

This is clearly an oversight, both in not involving the Parks Department in the planning and design of the project, and in not preparing a maintenance plan for the scheme that addresses all the services provided by the scheme. This is a risk for the long-term performance of the scheme, and highlights the need to develop the capacity and awareness within both the municipal departments involved (and particularly the custodian department) and the project design teams. It also highlights the need for institutional support for multi-departmental stakeholders in GI projects.

## Property price analysis

A property price analysis was conducted for the suburb of Atlasville for the period January 2004 to June 2015. Data on property sales in the suburb over this period were acquired from Lightstone Property to assess whether there is any correlation between flooding and property values, and any subsequent change following the implementation of the GI flood relief scheme. A potential benefit of GI projects is their ability to increase property prices because of the enhanced set of services provided.

The assessment was done with the backdrop of a national decrease in property values of approximately 10% between 2008 and 2010 (Global Property Guide, 2015). This needs to be considered in the overall findings of the price analysis. Data for the entire suburb was analysed, including properties with river frontage and those that fell within the pre-development 100-year flood line. First, values of all properties inside the 100-year flood line were compared with those outside the 100-year flood line for the period 2004–2015 (Figure 5.14 and Figure 5.15). The average property price for the entire Atlasville suburb was also plotted on each graph for comparison purposes.

Figure 5.14 and Figure 5.15 show a levelling of house prices after 2006 and a drop after 2008, but there is also a notable decrease in sales (density of points) after 2008. Whether this may be attributed in part to the start of flooding in February 2006 is not clear, but comments received through the community survey suggest that there may be a clear link.

Table 5.5 presents a perspective of the data in Figure 5.14 and Figure 5.15 in an attempt to detect trends that may link to the scheme. It displays the average values of properties in Atlasville inside and outside the 100-year flood line for key periods in the Atlas Spruit flood relief scheme. The first period (2004–2012) represents the period during which flooding in Atlasville was particularly prevalent. The second period (2012–2013) corresponds to the scheme's construction, and the third period (2013–2015) represents the period after the scheme was finalised. A comparison of both areas (inside and outside the 100-year flood line) over the full period (2004–2015) is also provided.

**Figure 5.14:** Atlasville property values inside the 100-year flood line (2004–2015)

**SOURCE:** Compiled from data supplied by Lightstone Property (www.lightstoneproperty.co.za)

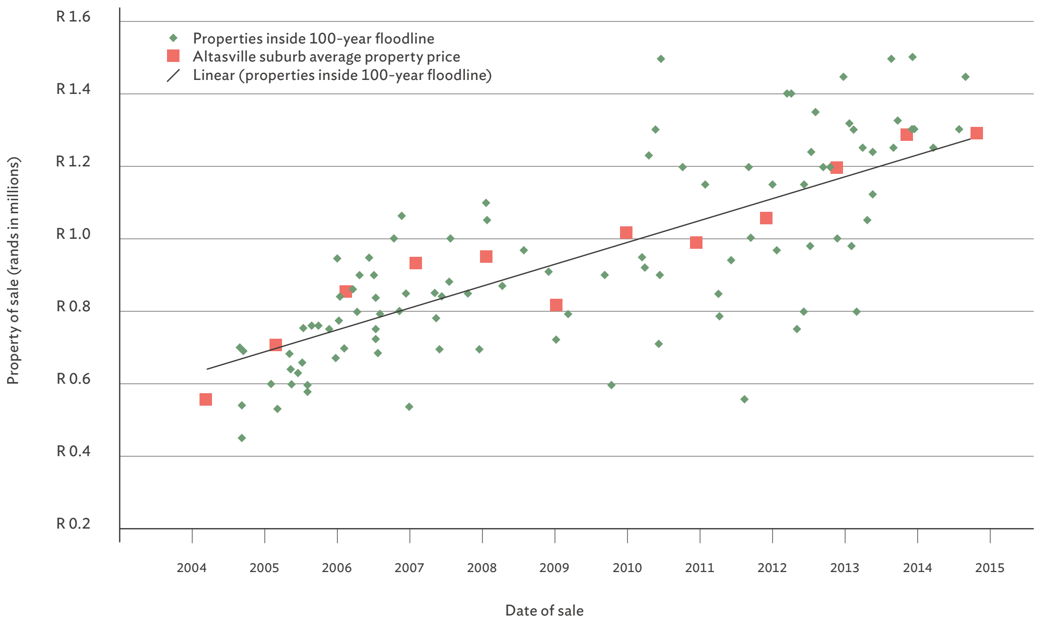



**Figure 5.15:** Atlasville property values outside the 100-year flood line (2004–2015)

**SOURCE:** Compiled from data supplied by Lightstone Property (www.lightstoneproperty.co.za)

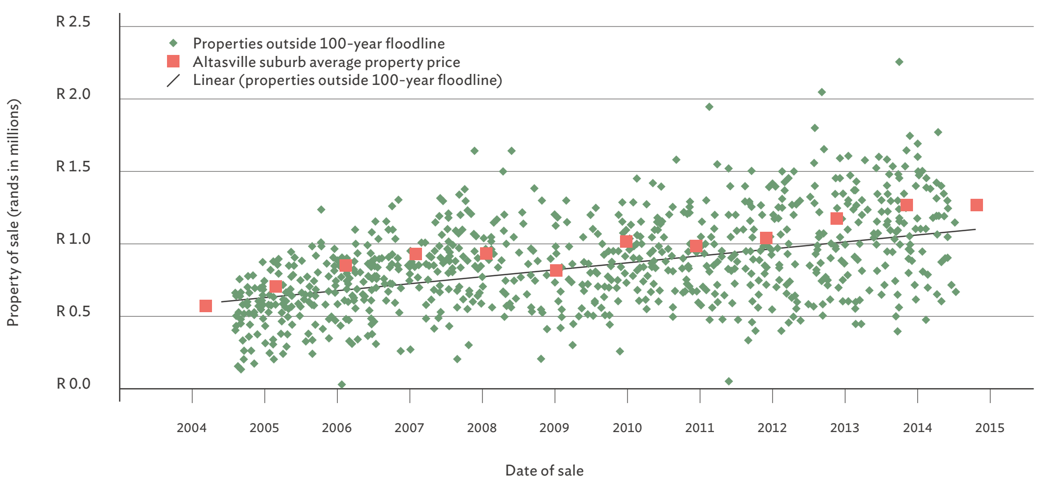


**Table 5.5:** Average property prices inside and outside the 100-year floodplain before the flood relief scheme, during construction of the flood relief scheme, and after the flood relief scheme

**SOURCE:** Compiled from data supplied by Lightstone Property (www.lightstoneproperty.co.za)

| Period | Location with respect to flood lines | Average property price | Difference (%) |
|---|---|---|---|
| **2004 to April 2012 (pre-scheme)** | Inside 100-year flood line | R849 000 | 8% |
| | Outside 100-year flood line | R781 000 | |
| **May 2012 to June 2013 (during construction)** | Inside 100-year flood line | R1 120 000 | 11% |
| | Outside 100-year flood line | R1 001 000 | |
| **July 2013 to 2015 (post-scheme)** | Inside 100-year flood line | R1 272 000 | 12% |
| | Outside 100-year flood line | R1 114 000 | |
| **Overall (2004 to 2015)** | **Inside 100-year flood line** | **R940 000** | **9%** |
| | **Outside 100-year flood line** | **R858 000** | |

Property values in the floodplain are generally around 10% higher than those outside the floodplain in Atlasville, including the period when flood risk was highest (between 2006 and 2012), although the difference is the smallest in this period. This correlates with other research demonstrating that being located closer to a recreational resource (in this case, the park and river) could offset the negative impact of flood risk on property values (Knight Frank, 2015; Lamond, 2009; Southwick Associates, 2013).

There is a distinct shift after the start of construction of Phase 1, where the average difference in property value between properties inside and outside the 100-year flood line rises from 8 to 12%. Whether this suggests that the market anticipated the scheme's flood risk benefits is difficult to say and a longer period of record post-scheme may be required to confirm a trend. However, it is unlikely that the increase can be attributed to the fact that it adopts a GI approach rather than a grey infrastructure approach. The reason being that the scheme was never marketed as a green scheme and the comparative benefits of a green scheme over a grey scheme did not emerge from the community survey. With an apparent increase in park visitors from the suburb in general, the outcome of the survey may even suggest that properties outside of the flood line may also increase in value as a result of the scheme, particularly due to the secondary services of habitat enhancement and public amenity value. If the multiple services of the flood relief scheme do influence property prices as anticipated, then the trend in increasing property values is positive. However, it is difficult to isolate the potential causes of a trend and test for them over such a short period.

Although the dataset is small, there appears to be a much sharper increase in property prices within the 100-year flood line during and after the construction period of Phase 1 compared with the properties in the wider suburb. The reasons for this were not specifically investigated. There had been extensive consultation about the project and its construction and so there would have been widespread knowledge in the community about the project. Thus it is possible the sharp increase could be associated with an anticipated positive outcome of the project. Nevertheless, these results should be treated with care, and property values will need to be monitored to see if the trend proves to be true.

## Summary: Green versus grey

The CBA comparing the green and grey schemes for each aspect in this case study is presented in Table 5.6. The ratio is presented as grey over green for the cost comparison where actual figures were available. A ratio of greater than one shows the green scheme to be preferred, while a ratio of less than one shows grey as the preferred option. The remaining components provide a qualitative indication of which scheme performed the best (or whether they were equivalent).

The overall evaluation is clearly in favour of the green scheme over the grey scheme. The capital cost comparison is an important base of support for the green scheme, but the other factors point to a scheme that provides important services to the local community and that these services are being appreciated. These multiple benefits go to the core of a GI approach.

It is worth repeating that the study team have tried to maintain a reasonably conservative comparison with the grey scheme while not overselling the value of the green scheme. Nevertheless, there will be some subjectivity in the assessment, and it is important that further work is done on assessing benefits of GI projects, including:

- Collecting data on other infrastructure projects in the region that demonstrate sustainable drainage or GI characteristics;
- Further developing the benefit assessment tools relevant to Gauteng municipalities;
- Encouraging community participation in evaluating the projects; and
- Monitoring the health, stability and overall performance of the projects over time.

**Table 5.6:** Cost–benefit analysis of the grey and green schemes, including the various aspects assessed

**SOURCE:** Fourth Element

| Aspect | Evaluation | Comment |
|---|---|---|
| **Capital cost** | $\frac{\text{grey scheme}}{\text{green scheme}}$ = 1.045<br>Green scheme = ✓ | The green scheme had a slightly lower cost than the grey scheme (by 4.5%).<br><br>While the capital cost of the green scheme is an actual Cost of Works, the one for the grey scheme is based on a concept design and thus accuracy will be reduced.<br><br>However, a conservative ('no frills') approach was adopted for the grey scheme and it is unlikely to be over-priced.<br><br>The green scheme is therefore, at a minimum, comparable to a grey scheme, but more likely to be lower cost. |
| **Maintenance (anticipated)** | Green scheme = ~ | Reeds and sediment are the main differentiators. The green scheme is more accommodating of sediment build-up, but will need reed management at least every two years in the short term. The system should stabilise in the long term.<br><br>The grey scheme should receive annual sediment and reed removal.<br><br>The evaluation is a prediction, but will be dependent on successful maintenance of the green scheme in the short term. |

| | | |
|---|---|---|
| **Ecological habitat** | Green scheme = ✓ | The overall benefit for ecological enhancement provided by Phase 1 is positive. The green scheme was compared with the pre-scheme condition, showing substantial improvement in habitat value. However, the bulk of the habitat improvement is seen in the in-stream condition, which would not be possible in the grey scheme. Hence the green scheme will perform better in this aspect.<br><br>The lack of specific ecological design suggests the green scheme could have been further improved with an ecologist on the design team.<br><br>One caveat is that there is a risk that reed development may return the stream to a condition similar to its pre-development state if maintenance is not undertaken. |
| **Community well-being (Recreation)** | Green scheme = ✓ | The community response to the scheme has been positive, with a preference stated for the green scheme.<br><br>Half of the respondents do not live along the spruit, implying they value the scheme as a general benefit to the area.<br><br>Some community members were not happy with the scheme, which flags concerns around the project's consultation process. This warrants further investigation and attention to be paid to consultation in future GI schemes. |
| **Property values** | Green scheme = ✓ | Both the grey and green schemes would have provided the same level of flood relief. If this is the dominant factor in values of houses in the original floodplain, then both schemes would carry equal weight. However:<br><br>• The community survey appears to place value in the stream and park in the community;<br>• Property prices in the floodplain have been generally higher than the rest of the suburb over time; and<br>• The rate of increase of property prices in the floodplain appears to be higher since the construction of Phase 1.<br><br>There is evidence in favour of the green scheme adding to property values, though the sample size is small. |

## Conclusion

The Atlas Spruit flood relief scheme emerged as a priority project to address flooding in Atlasville. In this case, flood relief was clearly the asset's priority service and the secondary services of ecological enhancement and public amenity only emerged during the concept design stage. Experience in implementing the project showed that, while the flood control service was correctly maintained as the overriding function, the secondary services probably did not achieve their full potential. As a result, maximum benefit of the scheme may not have been reached. An important consideration for future GI projects is to ensure the participation of key municipal departments as active stakeholders in the project, particularly in the feasibility and design stages.

To realise the benefits of any drainage-related scheme, but in particular a GI scheme that provides multiple ecosystem services, the fundamentals of the hydrology and hydraulics of the system need to be understood. Without the correct understanding, there is a strong possibility of over or under designing the scheme. This will directly influence the costs and benefits of the scheme and could undermine the value of GI projects. For the Atlas Spruit flood relief scheme, the effort made in the feasibility stage proved to be the vital part of the design process.

Municipal civil engineering should involve a level of public and community involvement, particularly on drainage and flood relief projects. However, for schemes providing multiple services, particularly those providing ecological and recreational services for community benefit, consultation processes need to be utilised to optimise design input for the community. If the community does not see the intended benefits, or does not use the facilities provided by the GI project to the full extent, then the benefits of the scheme will be diminished. In such cases it is possible for a grey scheme to be a better investment. The consultative processes for the Atlas Spruit flood relief scheme were fairly well established at an early stage in the project. While the majority of respondents to the survey reported the scheme to have had a positive outcome, the responses also highlighted issues that may imply the full benefit of the scheme will not be achieved as intended (e.g. a number of residents felt that the outcome of the scheme was negative). While it should not be the objective to please all community members, it is better to know there are disagreements before the design and the anticipated benefits are finalised. It is questioned whether the consultation process for this scheme was optimal, and whether more public amenity benefit could have been achieved.

Photograph by by Clive Hassall

Notwithstanding the above, it is important to note that many of the community concerns with the finishing of the site (e.g. topsoil, grass-cutting, stormwater outfall repairs, etc.) are in hand to be addressed in Phase 2. This will hopefully ease some of the community concerns about the scheme.

The municipality acknowledged the need to involve multiple departments as stakeholders in the project, and particularly departments who have long-term interests in seeing the success of the scheme. This will improve the design and the maintenance of the scheme, and ensure the long-term performance. This is important in realising the full benefits of the Atlas Spruit flood relief scheme. While the different municipal departments mentioned in this investigation have responded positively to the scheme, current institutional structures will impede their participation going forward. This places the scheme at some risk of losing benefits. Perhaps the most important example is the in-channel maintenance (removal) of reeds which will affect flood relief performance as well as habitat diversity.

Phase 1 has undoubtedly improved the condition of the habitat of the riparian zone of the stream and the scheme has improved the ecology in the two years since construction was completed. However, an opportunity was missed in the design to incorporate a wider range of habitat opportunities. This demonstrates the importance of having ecological and landscape expertise on the team from the start of any GI project.

The assessment of property values in Atlasville, and along the Atlas Spruit in particular, clearly supports the view that properties with river and parkland frontage generally attract higher property prices. This alone should be a strong motivation for investing in GI over grey infrastructure. Although the data analysed is a relatively small sample set, and it is possibly too early to see the full impact of the scheme on property values, the results are encouragingly supportive of a GI approach, with improved amenity and habitat along with flood relief.

As mentioned above, the outcome of this study found that the green scheme was a better alternative to an equivalent grey scheme for the same price. It is the study team's view that the gaps in the data available for the analysis have been treated conservatively, and that a subsequent assessment, with better data and a reasonable period after completion of the full scheme, will demonstrate an even better performance of green over grey infrastructure schemes. There are potential stumbling blocks to be faced, such as reed maintenance and interdepartmental cooperation, but there is a sense that the departments involved will work around these until the institutional structures are adapted to support GI developments. Similar assessments for other GI schemes are necessary to develop a database of what works and doesn't work on these projects within the context of Gauteng.

detention & infiltration basins

## Chapter 6

# Developing a 'green asset registry' to guide green infrastructure planning

*GILLIAN SYKES*

## Key points

- Incorporating green infrastructure (GI) into government asset registries has the potential to support spatial planning of GI as a component of the broader urban infrastructure network. Until green assets are included in asset maintenance plans, it will be difficult if not impossible to secure budget to ensure that the existing assets continue to perform at the required levels and standards of service.
- Green asset registries are intended to organise non-monetary information regarding the extent and condition of ecosystems, and expected ecosystem service flows.
- This chapter describes the conventional asset planning management and accounting frameworks in South Africa as well as some existing frameworks for developing green asset registries.[1]
- The following steps are recommended in terms of incorporating green assets into traditional asset registries: define green asset classes which pass the thresholds for recognition (ownership, benefits and value); identify all specified assets in terms of location and controlling entity; and decide what additional information needs to be tracked and recorded to allow the green assets (by asset class) to be managed successfully.
- Although there are numerous examples of where GI has been successfully implemented in South Africa, accounting for ecosystems and green assets is in its infancy. Two types of green asset registry frameworks that have the potential to support the development of a green asset registry in Gauteng include: The National Level Ecosystem Accounting and the 21st Century Water Asset Accounting.
- In light of the Gauteng context and the existing regulatory frameworks described thus far, an all-encompassing green asset registry may not be feasible in the short term. However, it may be more feasible to simultaneously implement a comprehensive green asset registry at the municipal or Gauteng scale and a utility-level asset registry.
- The proposed comprehensive asset registry would be GIS-based and cover an entire municipality or the Gauteng City-Region. This registry would support integrated municipal infrastructure planning and inform land use planning decisions on an ongoing basis.
- The utility-level asset registry would provide a mechanism for incorporating specific green assets into utility-level service asset registries. This registry would help green assets be recognised as 'assets in service' in order for budget to be allocated for their maintenance.
- This chapter has emphasised the importance of targeting the municipal engineer and piggybacking on existing asset management support initiatives. Municipal engineers are central to compliance with, and use of, asset registries.

1 This chapter presents the state of affairs at the time of writing (2016).

## Introduction

Given the need for recognising the role of green infrastructure (GI) and planning GI as a component of urban infrastructure networks, there is value in developing a spatially oriented registry of all significant green assets. Such a registry or dataset would assist in recognising the multitude of services provided by specific, spatially located assets (e.g. a wetland might purify water and reduce water treatment costs, provide a source of recreational activities, regulate flood waters, recycle nutrients, and provide a habitat for a variety of animal and plant species). The goal of a comprehensive green asset registry is to inform and influence overall municipal infrastructure planning.

The need for a green asset registry in the Gauteng City-Region (GCR) is motivated by the rapid and continuing pace of urbanisation, which means that land use management should recognise the need to protect ecological resources which are in danger of being lost along with the many ecosystem services they provide. However, there is also a need to identify land for housing and other developmental requirements, so strategic municipal-level trade-offs will have to occur. Despite earlier attempts to guide these decisions, this trade-off is currently occurring without recognising the value of ecosystem services and their subsequent loss, especially in terms of services like water and stormwater flows, air purification and temperature regulation. Green asset registries are intended to organise non-monetary information regarding the extent and condition of ecosystems, and expected ecosystem service flows.

While there have been many attempts over the past decade in South Africa to estimate the economic value of ecosystem services, this has not resulted in the incorporation of these assets into municipal budgeting processes. The lack of take-up of GI within municipal budgets can partly be attributed to a problem identified by Cartwright and Oelofse (2016), namely that the leap from economic to financial values is a difficult one to make. While the 'economic' rand value which has been attached to features such as wetlands has been important in raising awareness of the contribution made by ecosystem services, municipal budgets and accounting rely on 'financial' rands. As Cartwright and Oelofse (2016, p. 48) note, 'the economic value and broad investment case [...] does not automatically create an investment case for specific stakeholders when they focus on their own finances or narrow self-interest'. As Mander (2016, p. 60) contends, 'Although valuation is a necessary component for understanding the value of ecosystem services, it is insufficient in itself to ensure that GI is incorporated into the municipal decision-making process.' Valuation can lead to paralysis, with large environmental values that dwarf existing budgets (Cartwright & Oelofse, 2016), leaving municipal officials unsure of how to use or apply these values. On a financial level, municipalities have no incentive to incorporate these large 'total economic values' (which include both financial and non-financial values where there are no markets for specific goods and benefits) into their budgets.

So, while economic valuation has been a useful awareness-raising tool, it has not been effective in making an economic case for GI. In light of this, this chapter explores green asset registries as a potential way to make a case for investment in GI.

The ability to recognise green assets as municipal assets in their own right is a means of securing financing for these assets (e.g. through providing funding for maintenance in operating budgets). Until green assets are included in asset maintenance plans, it will be difficult if not impossible to secure budget to ensure that the existing assets continue to perform at the required levels and standards of service (as required by the guidelines in National Treasury, 2008a).

Dunsmore (2016) proposed developing a registry of green assets as part of the GI network as a key 'break-through action' to support grey-green engineered solutions. Recognising components of the GI network as formal assets owned by the municipalities may help to address some of the challenges facing infrastructure in South Africa, namely a shortage of skills and inadequate funding for maintenance. The issues around funding for maintenance are exacerbated by the fact that even where limited funds are allocated to maintenance, they often go unspent within that budget period due to poor municipal capacity and management. This chapter argues that incorporating GI into government asset registries could support spatial planning of GI as a component of the broader urban infrastructure network. The strength and coordination of the planning environment is essential to ensure that the contribution of green assets to the infrastructure network is optimised.

While the full economic value of a green asset targets strategic infrastructure investment planning and decision-making, individual projects are guided by the detailed project design or daily operations. A key challenge is in persuading relevant stakeholders (e.g. municipal line-function officials, engineers and technicians) that GI can address project requirements and can be implemented according to best-practice guidelines. In addition, evidence of successful GI projects can make further decisions to invest in GI easier.

*The need for a green asset registry is motivated by the rapid and continuing pace of urbanisation*

Photograph by Ihsaan Haffejee

## GI components for green asset registries

In ecosystem accounting, a distinction is made between green assets and ecosystem services, with ecosystem services flowing from the underlying green assets. These services can be broken down into three main groups – provisioning goods; regulating services; and amenity or cultural values – with supporting services a frequent fourth addition. As the United Nations (UN) System of Environmental-Economic Accounting (SEEA) (and the related Statistics South Africa [StatsSA] pilot referred to below) only refers to the first, we have limited our discussion to these three. Natural capital is another important concept in ecosystem accounting, which refers to the stock of natural ecosystems that yields a flow of valuable ecosystem services (European Commission Working Group [ECWG], 2015).

Table 6.1 provides a breakdown of the different components that can comprise a GI network and the relevance of these components for the GCR. This includes a coherent network of healthy ecosystems, multi-functional zones, natural landscape features, artificial features and man-made grey-green design solutions. In urban areas, artificial features and multi-functional zones are necessary to protect natural systems and encourage species movement. There are also a range of urban-specific interventions that can assist with maintaining biodiversity and the provision of ecosystem services.

The lack of a suitable accounting system for green assets is a fundamental barrier to the uptake of a GI approach. In response to this, the aim of this chapter is to explore the potential of integrating GI into existing municipal asset management and planning processes. To this end, the chapter outlines the requirements and possible methodologies for developing a green municipal asset registry for the GCR, and identifies opportunities for, and barriers to, including green assets in municipal infrastructure planning and asset management frameworks. This chapter is intended as a technical scoping study of existing asset registries and the potential for incorporating green assets into conventional accounting systems.

The research draws on examples of green asset registries and GI accounting systems both locally and internationally. The investigation contributes to understanding what is required to allow green assets to be planned and managed within municipal asset registries in the same way as traditional grey infrastructure. A discussion of conventional asset planning, management and accounting systems in South Africa is followed by a presentation of selected green asset accounting frameworks that have been developed both locally and internationally. The chapter then explores potential options for developing a green asset registry for Gauteng, and concludes with recommendations for future work to support the development and uptake of a green asset registry.

*In ecosystem accounting, a distinction is made between green assets and ecosystem services, with ecosystem services flowing from the underlying green assets*

**Table 6.1:** Breakdown of GI components and their relevance for the GCR

**SOURCE:** Adapted from ECWG (2015)

| GI components | Relevance for the GCR |
|---|---|
| Healthy ecosystems that exist inside and outside urban contexts create a coherent network of protected areas. | Due to the increasingly urban nature of the GCR, there is a need to preserve and restore the remaining extent of indigenous vegetation. |
| Multi-functional zones where land uses that help maintain or restore healthy ecosystems are favoured over other activities. | In the context of rapid urbanisation, where drainage, water quality and supply are of concern, it is necessary to provide quality green spaces for urban inhabitants that also minimise consequences of urban development. |
| Natural landscape features such as small watercourses, grasslands or wetlands, which can act as eco-corridors or stepping stones for wildlife. | This is important for improving biodiversity, and supporting pollinators, birds and other wildlife in the GCR. |
| Artificial features such as eco-ducts, eco-bridges, or permeable soil covers that are designed to assist species movement across insurmountable barriers (such as roads or paved areas). | Limited benefits for large mammals, but nonetheless very important for the movement and survival of smaller creatures and organisms given the highly transformed nature of the GCR. |
| Areas where measures are implemented to improve the general ecological quality and permeability of the landscape, such as swales (see Chapter 3). | Highly relevant to the GCR context given the scarcity of water, the anticipated high growth rate of future development, and the possible increased rate of runoff if non-permeable surfaces continue to be used. |
| Urban elements such as biodiversity-rich parks, permeable soil cover, green walls and green roofs that host biodiversity and allow ecosystems to function and deliver services. | Highly relevant for the GCR, particularly in the heavily built-up areas which have an overabundance of hard surfaces, resulting in higher urban temperatures, increased runoff (less absorption) and fewer environments that can support GI functions. |

## Conventional asset planning, management and accounting in South African municipalities

This section provides background to conventional planning, asset management and asset accounting in South Africa. Due to the complexity of these topics, they are only covered here at a relatively high level, while attempting to provide sufficient detail to advance the understanding of the hurdles to be overcome in developing a green asset registry. Additional detail can be found in a range of guidelines and manuals published by various national departments (e.g. National Treasury, the Department of Cooperative Governance and Traditional Affairs [CoGTA] and various other sector departments).

### Municipal asset accounting and asset registries

Some key elements of the existing accounting frameworks used for traditional grey assets are described briefly below. This provides a basis for evaluating the opportunities for, and barriers to, the development of a green asset registry for Gauteng.

#### *Definition of an asset registry and key components*

The Municipal Finance Management Act (MFMA): Local Government Capital Asset Management Guideline, developed by the National Treasury (2008a), provides a comprehensive explanation of the purpose of a municipal asset registry. For green assets to be integrated into municipal infrastructure networks, it would be optimal if they can be reported and tracked within the same framework. This section is a summary of this 2008 guideline, illustrating the key framework which would have to be applied to green assets to meet existing standards. An asset registry is defined as:

> *a complete and accurate database of the assets that is under the control of a municipality and that is regularly updated and validated. An adequate asset register is integral to effective asset management. It is the basis of an asset management information system and should contain relevant data beyond that required for financial reporting.* [...] *It stores information on each asset, which includes amongst others the cost price, date acquired, location, asset condition and expected life. It can also include information on current replacement costs. All assets owned and controlled by an entity must be recorded in an asset register, regardless of the funding source or value thereof.* (National Treasury, 2008a, p. 65)

A fundamental guiding principle for asset registries is to contain sufficient information for effective management. The type of information that is usually recorded in an asset registry for management purposes includes:

- Identification and location – What and where is this asset, and whom does it serve?
- Accountability – Who is accountable and how it is being safeguarded?
- Performance – What is its intended and actual level of service? This includes measures of capacity, current condition, estimates of useful life, and residual value (for assets which need to be replaced at some point). The regular assessment of the condition and performance allows the municipality to determine the ability of the assets to continue to provide services into the future.
- Accounting – How is it accounted for? This should include: valuation basis (such as historical purchase cost, current replacement cost); and depreciation parameters (such as useful life, remaining useful life, residual value, or impairment).
- Management and risk – How is it managed? How critical is it? This should include maintenance, engineering and operational data and may be summarised from sub-systems. Risk refers to threats to the expected operating life or performance of an asset. For example, inappropriate or excessive use over extended periods may increase the risk of requiring increased maintenance interventions, down time and reduction in the useful life of the asset.
- Acquisition and disposal – How was the asset purchased, constructed, or sold?

In light of the detailed information required, developing an asset registry from scratch takes time. Thus, an asset registry may be compiled in stages. The first stage involves compiling a database of all tangible assets controlled by a municipality, and includes simple information such as location, custodian and condition. Valuation and measurement issues can be resolved during the second stage. The asset registry guidelines provide a framework for the progressive implementation of a registry, which could be applied to the development of a green asset registry.

### *South Africa's GRAP17*

Under the Public Finance Management Act (No. 1 of 1999), local government in South Africa is expected to prepare asset registries in line with relevant accounting standards called Generally Recognised Accounting Practice (GRAP).[2] The introduction of the GRAP standards within local government has focused attention on asset management, and according to the National Treasury guidelines, local government is now required to 'identify, componentise, value and track the health of assets, to establish programmes and provide resources to care for assets, and to report on these matters' (Boshoff & Pretorius, 2010, p.1).

Under GRAP, the most relevant standard for GI is the accounting standard for 'property, plant and equipment' covered under GRAP 17.[3] GRAP17 is intended to guide how municipalities compile an inventory of production assets under their jurisdiction. Production assets are loosely defined as assets that provide a stream of benefits to the municipality. GRAP17 ensures that information is accurately recorded and updated in the financial statements of the municipality (Boshoff & Pretorius, 2010).

Asset registries are typically large and complicated, due to the need to 'componentise' or unbundle assets into their component parts so that they can be entered into the registry system. Unbundling allows for more accurate depreciation charges, based on the differing asset lives of the underlying assets.[4] This results in very large databases; for example, for Ekurhuleni in 2010, this was in the order of 1.2 million asset records (Boshoff & Pretorius, 2010). This size makes developing and maintaining an asset registry a costly and time-intensive activity. As a result, the current reality of municipal asset registries in South Africa is far removed from the end-state described within policy documents and guidelines.

### *Asset registries: Reality versus best practice in 2015*

As a matter of practicality, where municipalities have asset registries in place, there tend to be two main types: financial and technical. These serve different purposes and, as of the time of writing, are rarely integrated. Financial asset registries are used to track financial asset values and depreciation expenditure, and are therefore concerned primarily with the depreciation flows which need to be reflected on the relevant department's annual expenditure budget. By contrast, technical asset registries, where they exist, are developed and maintained within a specific utility or service department to meet their particular service needs. In some cases, particularly in the case of metropolitan areas which previously consisted of a number of smaller municipalities, it may consist of multiple registries that are not linked and are housed in different software systems (K. Walsh, pers. comm., 2015). These technical asset registries are intended to track the location, value and condition of each asset, but are frequently incomplete, out of date, or do not exist because of the onerous task of building and maintaining these registries.

The current status of asset registries in South Africa varies between municipalities and departments. In 2008, the National Treasury noted that, while some municipalities had initiated projects to develop asset registries, the information was still generally inadequate and did not fully comply with the accounting standards, and were therefore subject to audit queries and qualification (National Treasury, 2008a).

2 The current list of applicable standards is available at http://www.asb.co.za/GRAP/Standards/Approved-and-effective

3 See Deloitte (2012) for more information on the entire GRAP system.

4 Readers wanting to know more about this process are directed to National Treasury's Local Government Capital Asset Management Guideline (2008a) in terms of the MFMA.

## Municipal infrastructure planning

In order to understand how to integrate GI most effectively into traditional grey infrastructure networks, it is first necessary to understand how these networks are planned. While policy and practice currently diverge, it is nonetheless important to be aware of the approaches that municipal officials are required to take in this regard.

Municipalities need to plan for the level of services they require and how they will use available funds to expand and maintain these services. In some cases, policy documents and guidelines recommend plans, but as these are not statutory, municipalities are not obliged to follow them. For example, while the CoGTA (2006) and the Development Bank of South Africa (DBSA, 2008) infrastructure management guidelines talk about plans such as the Comprehensive Infrastructure Plan (CIP), or the Infrastructure Investment Plan (IIP),[5] these plans have no statutory status.

Although not a statutory plan, the widely used Infrastructure Asset Management Plan (IAMP) is intended to set out the sector's needs and priorities, levels of service, future demand, capital works, operations and maintenance programmes and strategies, and funding plans. It should be updated on an annual basis. Municipalities are expected to draw their IAMPs together into one consolidated plan, the CIP. The CIP contains summarised information from the IAMPs and provides the core infrastructure inputs to the Integrated Development Plan (IDP). This consolidated view of the state of infrastructure in the municipality allows strategic decisions to be made about service levels and funding decisions.

The only statutory planning process which is integrally linked to municipal budgeting processes is the IDP. The IDP is defined in the Municipal Structures Amendment Act (MSA, No. 33 of 2000) as 'a single, inclusive and strategic plan for the development of the municipality which links, integrates and coordinates plans; aligns the resources and capacity of the municipality with implementation of the plan; forms the policy framework and general basis on which budgets must be based' (Section 25).

## Existing municipal asset management planning frameworks

Asset management planning is a sub-component of the broader infrastructure planning process and, as a more technical exercise, goes into finer detail than strategic infrastructure planning. A number of capacity-building and regulatory initiatives inform municipal asset management and are led by various government departments.

*Not all of these plans and guidelines are statutory, and municipalities have discretion in using them*

5 The IIP places emphasis on capital expenditure requirements, including renewal, capital finance options and financial viability. The DBSA guideline is supplemented with an IIP training programme, including a module on asset management (DBSA, 2008).

These initiatives, in combination, seek to help municipalities follow a structured approach to their asset management and finance as well as to guide their prioritisation of maintenance projects according to a life-cycle approach. Some key initiatives are listed below, together with the relevant department or institution:

- MFMA Local Government Capital Asset Management Guideline (National Treasury, 2008a);
- MFMA Municipal Asset Transfer Regulations (National Treasury, 2008b) and the MFMA Budget Formats Guide (National Treasury, 2008c);
- Government-wide Immovable Asset Management Policy (Department of Public Works [DPW], 2005);
- Guidelines for Infrastructure Asset Management in Local Government 2006–2009 (CoGTA, 2006);
- Comprehensive Infrastructure Planning Framework[6] by municipalities (DPLG, 2008);
- IIP and the Guidelines for Municipal Services Infrastructure Investment Planning (DBSA, 2008); and
- National Water Services Infrastructure Asset Management Strategy (Department of Water Affairs [DWA], 2009).

However, as discussed in the preceding section, not all of these plans are statutory (e.g. the CoGTA and DBSA infrastructure management guidelines), and municipalities have discretion in using these guidelines. Asset management at the municipal level in South Africa is largely regulated by the MFMA (including the Local Government Capital Asset Management Guideline [National Treasury, 2008a]) and GRAP17 (National Treasury, 2008d). As specified in the National Treasury's guide to municipal financial management (National Treasury, 2008a, pp. 22–23):

> *The development of asset management plans is an interactive process that starts with the identification of service delivery needs and ends with an approved 'multi-year' budget linked to the Service Delivery and Budget Implementation Plan (SDBIP) based upon the most cost-effective method of delivering that service. During the process the asset manager should:*
>
> - *consider the service-level requirements identified from the IDP development process;*
> - *review the current levels of service provided from the relevant assets;*
> - *conduct a 'gap analysis' of the required vs. current service levels;*
> - *identify a range of options to resolve that service-level gap;*
> - *conduct a preliminary assessment of the feasibility of various options;*
> - *develop a business case for the most feasible option or options. This business case should include:*
>   - *the proposed service delivery option,*
>   - *identified benefits and identified needs,*
>   - *a full life-cycle costs forecast,*
>   - *credible revenue forecasts including other funding sources,*
>   - *a risk assessment across the whole life cycle of each option, and performance measures that can be used to assess the success of the options and implementation progress.*

## Incorporating green assets into traditional asset registries

Based on the general definitions and the existing planning, management and accounting practices related to municipal asset registries, this section explores how these can be applied to green assets for their incorporation into traditional asset registries. The following steps are recommended in terms of incorporating green assets into traditional asset registries:

1. Define green asset classes which pass the thresholds for recognition.
2. Identify all specified assets in terms of location and controlling entity.
3. Decide what additional information needs to be tracked and recorded to allow the green assets (by asset class) to be managed successfully.

6 Boshoff (2009) provides a useful discussion of the differences between the CMIP and CIP. In short, the CMIP was retitled and became the CIP. While the intention remains the same, there are some important differences to the original recipe, namely the absence of the previous requirement for the preparation of asset registers and sector-based asset management plans to inform the CIP.

*Threshold requirements for an asset to be recognised in financial accounts*

By definition, an asset must be controlled by the entity in order for it to be recognised in financial statements, or to be included in traditional financial asset accounts. Municipalities have to control an asset in order to include it in their asset registry. Control in this case means the financial ownership, or decision-making ability regarding the use, or disposal, of an asset. This may pose a significant challenge for the inclusion of green assets in traditional asset registries. At the smallest scale, for example, while a tree on private land may be providing the same benefits as a tree in a public park, that tree on private land is under the control of the private land owner, who may decide to keep it, chop it down or trim it as they see fit. While there are theoretical mechanisms for working around this – such as putting an agreement in place between the land/tree owner and the municipality – they require additional effort, expense and monitoring.

Once this ownership threshold has been met, there are two further requirements an asset must meet before it can be recognised in formal asset registries, namely, the inflow of benefits to the controlling entity must be probable, and the cost or value can be measured reliably (National Treasury, 2014).

While the first requirement is relatively easy to meet, there is currently limited agreement on valuation methodologies for GI, which makes the second requirement a significant hurdle. The role of financial versus economic valuation methods also needs to be clarified (see Cartwright & Oelofse, 2016; Mander, 2016).

The difficulty of accounting for green assets has already been acknowledged by existing National Treasury guidelines. For example, the 2008 Asset Management Guideline contained only one mention of 'green assets' and this was in a section on 'Valuing environmental reserves' in the annexures. The guideline (National Treasury, 2008a, Annexure A1, p. 10) identifies the uncertainty around how to value green assets and this should be informed by the development of 'recognition criteria':

> *Municipalities usually manage environmental or public reserves like beaches, estuaries, nature reserves, wetlands, etc. The question arises as to how to value these areas of land. From an accounting perspective, a municipality needs to apply the recognition criteria, in particular the criteria of 'measured reliability' and 'control'.*

An update of GRAP 17 in 2011 contains more information on how to account for different green assets. It also includes a decision tree to help establish which accounting standard is relevant to different classes of green assets (Figure 6.1). In the National Treasury decision tree, if the answer to the statement on the left is positive for a specific green asset, the relevant GRAP standard is referenced. If a green asset fails to meet any of these characteristics, then there is no current framework for reporting on it.

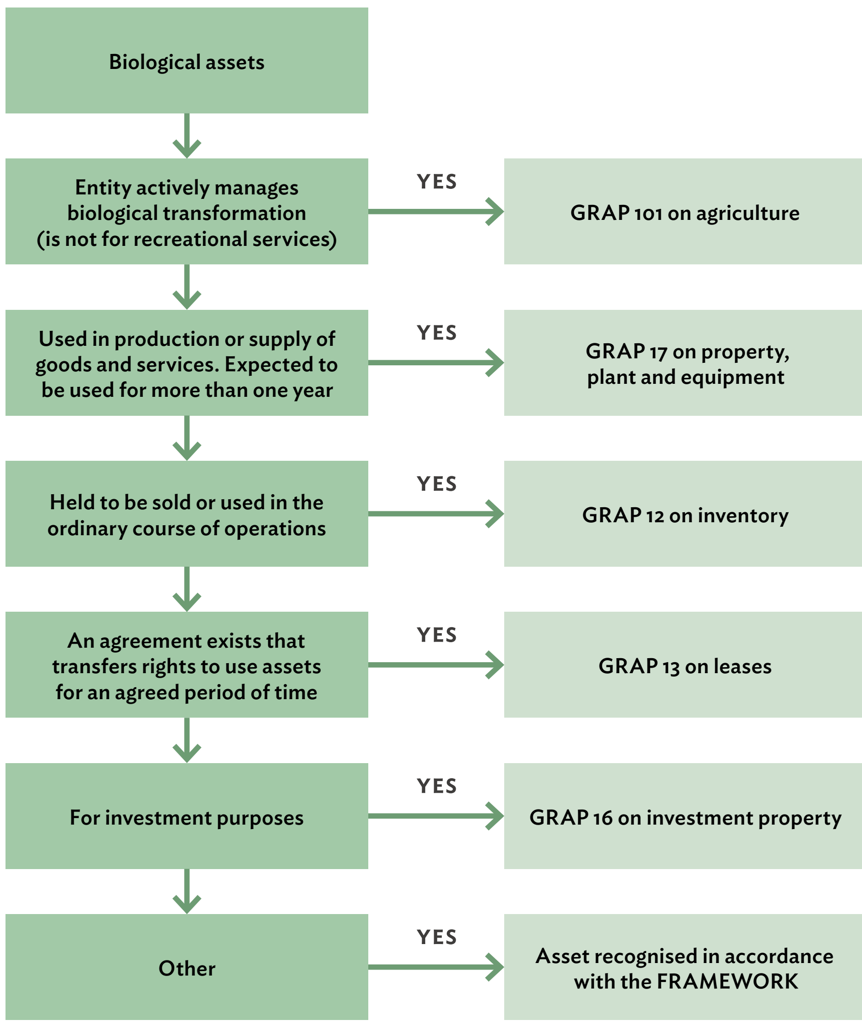
If a green asset passes the recognition criteria, and is used in the production or supply of goods and services for more than one year, GRAP 17 accounting principles can be applied. The 2014 version of GRAP17 specifically includes trees in public parks as municipal assets. However, a private tree under the control of another entity (such as a private individual) would not pass the initial criteria of being under municipal control. Therefore, if GI elements can clearly be identified as a specific service asset, then they can be accounted for.

Although many green assets will be excluded by these criteria, there is a sub-set of green assets that can immediately meet them (such as man-made green assets, focusing on their primary function or service only).

*There is currently limited agreement on valuation methodologies for GI*

**Figure 6.1:** Decision tree to identify the applicable standard of GRAP to apply to green assets

**SOURCE:** National Treasury (2014, p. 10)



Photograph by Mark Lewis

## Using standard accounting terms to describe green assets

This sub-section provides an overview of some key accounting concepts which may apply to green assets that have passed the recognition thresholds listed above of being under municipal control, providing a stream of benefits (identified as needed within the IDP) and can be measured reliably.

Traditional grey assets generally have a useful asset life and have to be replaced after that time. The asset life is based on averages for different asset classes, such as three years for a laptop computer and 50 years for a bridge. This provides the period over which the asset is expected to provide a flow of benefits or services, also known as the depreciation period. The concept of depreciation is linked to the concept of asset replacement: if you know you have to replace an asset in three years, it is necessary to budget accordingly, and depreciation is therefore included as an expenditure item on utility accounts.

Depreciation is the systematic allocation of the depreciable amount of an asset over its useful life. Useful life is the period of time that the entity expects to use an asset while the economic life is the actual life span of the asset. The depreciable amount is the cost of an asset, or other amount substituted for cost, less its residual value. If the residual value of an asset increases to an amount equal to, or greater than, the asset's carrying amount or book value, no depreciation is recognised.

In some cases, green assets do not need replacement or have limited asset lives, as do traditional grey assets. Green assets do not lose value in the same way as other assets. The residual value of natural green assets, as opposed to man-made green assets, will always be equal to, or greater than, its 'carrying amount' (or cost less accumulated depreciation since it was acquired), which means that these natural green assets will not be depreciable assets. This is not unusual, as not all assets are subject to depreciation. Land, for example, is not treated as a depreciable asset. Standard asset accounting therefore has established mechanisms for recognising assets with different properties and characteristics.

The ability to account for GI may also affect the ability of utilities to plan for infrastructure. If an asset can be capitalised, it means that the cost of that investment can be spread over a number of years rather than being expensed in one year. The current capitalisation threshold is R5 000, meaning that assets costing above this can be accounted for over multiple years (based on formal asset life averages which are supplied), while assets costing less than R5 000 are expensed over one year, and are not depreciated over time.

Different green asset classes could or should receive different accounting treatment, at least in formal financial accounting terms. For example, a wetland fails to meet the tests mentioned above for inclusion in traditional asset accounts in that there are currently no reliable or standard valuation methods that are appropriate for this context. On the other hand, a swale has an identified cost, a useful asset life, and is clearly owned by the utility or municipal entity. There is no reason why it cannot be incorporated into existing asset registries.

There are at least two broad categories which can be recognised as municipal assets, including:

**Depreciable green assets:** Man-made green assets (such as permeable paving or swales) which meet the threshold requirements for recognition, can be accounted for along with traditional grey assets and treated as depreciable assets;

**Non-depreciable assets:** Green assets and features (such as a wetland) which provide an indefinite stream of services, thereby maintaining or increasing their value.

Further research is required to understand how different green assets could be unbundled into different asset classes and how these green assets should be accounted for. In addition, further clarity is needed about how green assets can be quantified in a way which enables direct cost and reliability comparisons with existing grey infrastructure alternatives, and recognition of GI as municipal assets.

In traditional asset accounting, the expected flow of benefits (in terms of capital services) is calculated for a single asset. The pattern of expected flows provides the basis for valuing the asset, determining flows of income and depreciation. At the simplest level, if a computer is assumed to be at the end of its useful life and due for replacement in four years, this asset is depreciated at an annual rate of 25% of its (replacement) value over that period. At the end of its life, it is assumed to have no residual value.[7]

However green assets differ from traditional grey assets in four ways:

1. Green assets can regenerate.
2. A single green asset may generate varying groups of ecosystem services over a series of accounting periods. In contrast, even if a single traditional grey asset is sold on (such as a laptop to someone who does not need the latest model), it only ever provides one service over accounting periods which do not overlap.
3. The ecosystem services from a green asset may be used by a range of different users, from households to the broader community, whereas traditional grey assets are only used by the economic owner of the asset (a computer shared by many students is owned by the school).
4. There is not a one-to-one relationship between the capacity of a green asset to generate ecosystem services and the actual use of ecosystem services in economic and other human activity. In the case of traditional grey assets, their capacity to generate capital services is either fully used or it is assumed that use relative to capacity exists at a relatively stable level. Situations where there are permanently underused traditional grey assets are assumed to be uncommon over a business cycle, whereas for green assets such situations can easily arise (United Nations [UN], 2014).

*Implications for developing a green asset registry in the GCR*

One of the greatest challenges facing the implementation of green asset registries is that it is not currently required of municipalities, nor do they have to report to other spheres of government about it. In the face of severe capacity constraints and initiatives such as the 'Back to Basics' campaign,[8] this immediately side-lines GI issues from serious consideration in existing processes and decision-making.

While green asset registries have been identified as a way of ensuring that GI is allocated sufficient budget for maintenance, it should be noted that inadequate budget for maintenance is a problem not only across all sectors in South Africa, but is recognised internationally as a challenge (Jaffe, 2014; Pagano, 2012; Rioja, 2012; World Economic Forum [WEF], 2014).

Given the state of asset management and maintenance in South Africa currently, the full benefits of recognising GI as assets in their own right are unlikely to be realised until general problems with asset management have been resolved. However, there remains a valuable opportunity to ensure that GI is included in any capacity support which is provided to municipalities. This should include partnering with organisations such as the Institute of Municipal Engineering in South Africa to ensure that GI concepts are included in best practice guidelines issued to municipal engineers.

*Inadequate budget for maintenance is recognised as a challenge both in South Africa and internationally*

7 It has no useful life left from the perspective of the company, which now has to purchase a new computer.

8 'Back to Basics' was launched in 2014 as an urgent action plan to support local government. This plan focuses on a range of issues including basic service delivery, good governance and ensuring sound financial management and accounting.

Box 6.1 provides some insight into how municipal engineers can be encouraged to consider green assets in a similar light to traditional grey assets. Developing GI pilots which compare GI to traditional infrastructure in terms of conventional service metrics and reliability is essential to demonstrating the value of GI (see Chapter 5).

Table 6.2 shows how existing elements of the National Treasury Municipal Financial Management policy can be used to incorporate GI concepts. The two left-most columns are taken from National Treasury's guide to municipal financial management (2008a), while the column on the right identifies the implications, challenges or opportunities for developing a green asset registry.

Given the municipal planning, budgeting and accounting challenges discussed previously, two types of green asset registry frameworks, which have been developed internationally and deemed to be relevant to the Gauteng context, are outlined in the following section.

**Box 6.1:** How to encourage municipal engineers to consider GI options

The International Infrastructure Management Manual (IIMM), developed in New Zealand and Australia, contains good practice guidelines for municipal infrastructure management, and is recognised as a source of best practice globally, as well as in South Africa. It is interesting to note that in a review of all publicly available material in the IIMM 5th edition (Institute of Public Works Engineering Australasia [IPWEA], 2015), there is no mention of 'green' or 'ecological' infrastructure. However, the latest update does speak to infrastructure resilience, which focuses on the sustainability and cost of infrastructure. It is this lens of resilience which appears to bring engineers on board with the best entry point for integrating GI into traditional grey asset networks, namely, how to prolong the life of traditional infrastructure, or reduce the cost of providing the same service. The resilience framing also speaks to current initiatives for climate adaptation in response to global warming through ecosystem-based adaptation, which opens up avenues for promoting the use of GI.

Photograph by Christina Culwick

**Table 6.2:** Comparison of key asset questions which need to be addressed during the IDP process and the associated relevance for a GI approach.

**SOURCE:** Adapted from National Treasury (2008a, p. 29)

| IDP questions | Tool/Task | Relevance for a GI approach |
|---|---|---|
| **What assets exist and where are they?** | Create an inventory or asset registry to record assets | Completing an asset registry for all green assets will enable and support recognition and inclusion of these assets within the IDP. |
| **What are existing assets worth?** | Asset valuation (based on financial replacement costs for traditional infrastructure as opposed to the ecosystem services definition of replacement costs) | Methods of valuing green assets will vary according to the class of green asset. For example, man-made GI features such as swales have a cost and lifespan which enables them to receive the same accounting treatment as traditional infrastructure assets.<br><br>While it is possible to value natural green assets such as a wetlands and streams using a variety of economic valuation techniques, there is no single accepted financial or monetary value for these assets due to the absence of a market. |
| **What is the condition of the assets and what is their expected remaining useful life?** | Condition assessments | This requires the unbundling of differing services provided by a green asset, and the identification of specific attributes so the ability of the asset to provide these services can be tracked (e.g. water provision). |
| **What is the expected or required level of service from a particular asset?** | IDP development | Green assets and their services need to be linked to a specific IDP goal or priority. For example, if stormwater management is an issue in a specific community, the use of swales and wetlands would be appropriate in addressing the issue. |

| | | |
|---|---|---|
| **How can that level of service be achieved?** | Asset management and operational plans | Green assets need to be part of line-function department planning and recognised as an acceptable alternative (not an inferior level of service). |
| **What additional assets do you require?** | Gap analysis | Green assets need to be recognised by the relevant planning engineers as part of the acceptable 'tool-kit' of available infrastructure options. |
| **How much will the level of service cost and when (or how) can it be funded?** | Multi-year capital and operating budgets | The financial costs associated with maintaining the specific green asset (and the service it provides) must be calculated. Activity-based costing is encouraged by the National Treasury for all activities. |
| **Ensure that the level of service is 'financially sustainable'.[9]** | Fiscal policy, short- to long-term financial plans | The relevant part of the green asset must be recognised as part of the specific line-function list of assets in service (e.g. the water division's asset registry), and be recognised as part of the expenditure base. |
| **How will the delivery of the service be monitored?** | Service delivery and budget implement plans, and performance management system and performance agreements | This is linked to the unbundling of green assets into the services relevant for municipalities, and will have to be developed in conjunction with the municipal officials and engineers. |

9 'Financially Sustainable, in relation to the provision of a municipal service, means the provision of a municipal service in a manner aimed at ensuring that the financing of that service from internal and external sources, including budgeted income, grants and subsidies for the service, is sufficient to cover the costs of: the initial capital expenditure required for the service; operating the service; and maintaining, repairing and replacing the physical assets used in the provision of the service' (Section 1 of the Municipal Systems Amendment Act of 2000).

## Existing frameworks for GI accounting and asset registries

Although there are numerous examples of where GI has been successfully implemented in South Africa, accounting for ecosystems and green assets is in its infancy. Two types of green asset registry frameworks have been identified that have the potential to support the development of a green asset registry in Gauteng. These include the National Level Ecosystem Accounting and the 21st Century Water Asset Accounting. These frameworks are relatively recent and are novel in the concerns that they address.

### National Level Ecosystem Accounting

The UN Statistical Commission's System of Environmental-Economic Accounting (SEEA) Central Framework was developed over several years of international cooperation and was published in 2012. It is a 'conceptual framework for understanding the interactions between the economy and the environment, and for describing stocks and changes in stocks of environmental assets. [... It] brings statistics on the environment and its relationship to the economy into the core of official statistics' (UN, 2012: x).

The focus of the framework is on provisioning goods (such as mineral and energy resources, timber, water and land) and covers both natural and cultivated resources. The framework acknowledges that the pressures on the various types of services may be quite different. The basic resource accounts that are fundamental to ecosystem accounting and that need to be developed in each country, include land accounts, carbon accounts, water accounts, soil and nutrient accounts, and biodiversity accounts. The framework provides ways of accounting for these various resources (UN, 2012; UN, 2014).

The SEEA Experimental Ecosystem Accounting, released in 2014, covers the same green assets but considers the benefits or services obtained from green assets, including both material and non-material benefits. The measurement focus is on ecosystems, and it considers non-material benefits from the indirect use of environmental assets, such as water purification, carbon storage and flood mitigation (UN, 2014).

While both the SEEA Central Framework (UN, 2012) and the Experimental Ecosystems Accounting (UN, 2014) systems are designed to tie into official national statistics, they also provide principles and a common language which can be applied at the sub-national level. They provide an integrated accounting structure for ecosystem services and ecosystem conditions in both physical and monetary terms. While the SEEA Central Framework is generally a-spatial, concerned primarily with the stocks and flows of green assets at the national level, the SEEA Experimental Ecosystem Accounting system recognises that spatial areas must form the basic focus for measurement. The Experimental Ecosystem Accounting system recognises that knowing the location of assets is important from a policy perspective, as it can help to identify key resources spatially and where they are under pressure. A GIS-based system is expected to be the basis for generating these accounts because GIS systems are able to locate assets spatially and include a range of information related to the respective assets.

#### *Units of measurement in Ecosystem Accounting*

Three different, but related, spatial units are defined in SEEA Experimental Ecosystem Accounting (UN, 2014) to accommodate the different scales and methods used to collect, integrate and analyse data. Depending on the attribute being measured, direct measurement can occur at any level. These spatial levels are shown in Table 6.3, together with their relevance for the Gauteng context.

**Table 6.3:** Relevance of the Experimental Ecosystem Accounting (EEA) spatial units to the GCR

**SOURCE:** Developed from UN (2014)

| EEA spatial unit | Definition | Relevance to the GCR |
|---|---|---|
| **Basic spatial units (BSUs)** | The smallest units. Ideally an area of about 1 $km^2$, typically identified by overlaying a grid on a map of the relevant territory. BSUs may also be land parcels delineated using a cadastre or remote-sensing pixels. | This could be drawn from a satellite photograph of the GCR with a 1 $km^2$ grid overlay, or be based on planning cadastral boundaries. Cadastral boundaries would draw directly from existing municipal planning data-layers, and could help to identify the type of ownership (private, spheres of government, etc.).<br><br>This also opens the possibility of using remote-sensing layers, which could be developed and populated quite rapidly. |
| **Land cover/ ecosystem functional units (LCEUs)** | LCEUs are differentiated on the basis of ecosystem characteristics, which generally include land cover and soil type, climate or altitude. | Each BSU should be allocated one of the relevant ecosystem types. |
| **Ecosystem accounting units (EAUs)** | EAUs are defined according to the purpose of analysis, and therefore are meant to take account of administrative boundaries, environmental management areas, large-scale natural features (such as catchment areas) or other areas relevant for reporting purposes. | Using existing municipal or provincial boundaries could maximise data-sharing opportunities, mutual learning, and enable the use of this information for municipal planning processes. This needs to be in alignment with the units of measurement and reporting. However, if the underlying captured data (BSUs or smallest units) are 'tagged' correctly, it should be simple to generate a map based on the relevant scale of analysis (e.g. catchment management or municipal areas). |

*These frameworks provide an integrated accounting structure in both physical and monetary terms*

The land cover/ecosystem functional unit (LCEU) is the basis of accounting of green assets. It is possible for a number of LCEU classes to be present within a single accounting unit (e.g. Ekurhuleni Metropolitan area). As provisioning services and regulating services (such as water purification) are closely associated with land cover classes, an LCEU provides a useful base unit for ecosystem accounting. The set of land cover classes recognised by the UN Framework (UN, 2014) provide a starting point for developing relevant units for green asset accounting (Table 6.4). While Table 6.4 provides a starting point, not all of the categories are relevant to the GCR, and it is recommended that the list of relevant land cover classes be developed in conjunction with StatsSA and the South African National Biodiversity Institute (SANBI) to ensure a standardised set of measures. This will maximise the potential of data-sharing.

**Table 6.4:** Provisional land cover/ecosystem functional unit (LCEU) classes

**SOURCE:** UN (2014, p. 27)

| LCEU classes |
|---|
| Urban and associated developed areas |
| Medium to large fields of rain-fed herbaceous cropland |
| Medium to large fields of irrigated herbaceous cropland |
| Permanent crops, agriculture plantations |
| Agriculture associations and mosaics |
| Pasture and natural grassland |
| Forest tree cover |
| Shrub land, bush land |
| Sparsely vegetated areas |
| Natural vegetation associations and mosaics |
| Barren land |
| Open wetlands |
| Inland water bodies |

*StatsSA and developing a national framework approach to ecosystem accounting*

Based on the National Treasury guidelines, the differences between traditional grey assets and green assets mean that green assets have to be accounted for differently, and in particular they have to deal with green assets that provide numerous benefits or services (see the section from page 133). Both the SEEA Central Framework (UN, 2012) and SEEA Experimental Ecosystem Accounting (UN, 2014) provide frameworks for beginning to recognise the value provided by GI, and work has already begun in South Africa to adapt them to meet our circumstances.

StatsSA has already started publishing a National Accounts: Environmental Economic Accounts Compendium, which currently reports on energy, fisheries and mineral stocks and flows, but only in physical terms, not in financial terms. To date, it has focused on the 'provisioning' services in these national accounts, but the 2015 report includes an exploratory chapter on ecosystem accounting, which expands the accounts to include regulating services (StatsSA, 2015).

In 2013, StatsSA began a partnership with SANBI to develop experimental ecosystem accounting for South Africa, with the Council for Scientific and Industrial Research (CSIR) and the Department of Water and Sanitation (DWS) providing support to the pilot project. The first experimental phase focuses on national river ecosystem condition accounts as well as integrated land and catchment accounts in one province. Most data are sourced from the DWS and the National Freshwater Ecosystem Priority Areas (NFEPA) project, with data on ecological conditions being reported at a range of spatial scales.

South Africa is one of seven pilot countries selected by the United Nations Statistical Division (UNSD) to showcase the SEEA Experimental Ecosystem Accounting (UN, 2014). The UNSD is partnering with South Africa's Water Research Commission (WRC), to explore 'avenues to develop a framework, methodology and data sources to start water accounts for South Africa' (StatsSA, 2015, p.2). The first phase commenced in August 2014 and was scheduled to be completed in June 2015 (StatsSA, 2015).

These provide an important basis for developing relevant scales and units for the GCR. The advantage of developing a comprehensive registry of green assets within the GCR, which is compatible with the UN Central Framework (UN, 2012) outlined above, is that it capitalises on work that has been done in South Africa to date and that has wide international support. At the very least, this existing work may provide the basis for a 'first-cut' system of ecosystem accounts for the GCR. In addition, the Spatial Data Infrastructure Act (SDIA, No. 54 of 2003) is intended to facilitate the sharing of spatial information. As the SDIA is implemented through the National Spatial Information Framework (NSIF),[10] this presents an opportunity to make sure that cost-saving and coordination are maximised.

Photograph by Kirsty Mackay

10 'The National Spatial Information Framework (NSIF) is a directorate established in the Department of Rural Development and Land Reform, within the Branch: National Geomatics Management Services to facilitate the development and implementation of the South African Spatial Data Infrastructure (SASDI), established in terms of Section 3 of the Spatial Data Infrastructure Act (SDI Act No. 54, 2003). The NSIF drives the development and implementation of the SASDI, intended to eliminate data capture duplication and improve the access to, discovery, retrieval, sharing and interoperability of public sector spatial information' (http://www.sasdi.gov.za/sites/SASDI/Pages/nsif.aspx).

## 21st Century Water Asset Accounting

Given the identified financial accounting constraints based on the thresholds for asset recognition (outlined in the section on page 134), it is apparent that not all assets can be incorporated in traditional accounting. For those that do pass the first hurdle of control (municipal ownership) and offer more than a one-year stream of benefits or services, they may still not pass the final hurdle of a reliable method of valuation. The Water Environment Research Foundation (WERF) pilot provides a possible solution to this problem.

WERF funded a research project in three case-study municipalities in the United States of America to develop and advance accounting practices for GI by addressing the following questions (Pickle et al., 2014, B-1):

- *How can utilities and financial oversight organizations work together to account for green infrastructure assets in a utility financial statement?*
- *How do utility investment priorities and plans change when utilities account for the value of watershed and GI services?*

The pilot case-study report provides a 'how-to' guide for GI accounting in the operating environments of drinking water, stormwater, or wastewater management. The project developed new accounting methods to help public water utilities more accurately assess the 'value' provided by their green assets. Note that the focus was on individual utilities, or line-function departments, and not on creating a comprehensive green asset registry. In the case-study municipalities, the GI accounting framework was included in the supplementary disclosure section of the municipal annual financial report. This was because these sections are not audited and therefore not subject to nationwide standards. Two types of frameworks were developed during the pilot including:

1. A conventional balance sheet approach, where green assets are recorded in a format similar to other assets, with changes in assets measured as stocks and flows.
2. An ecosystem services model, which records a green asset under a utility's control and the specific services that asset provides. Significantly, it is designed to accommodate technical metrics (e.g. reduced runoff measured in litres of water) as well as monetary values (Pickle et al., 2014).

### *The balance sheet approach*

The balance sheet approach reports data on GI in a format similar to a utility's financial statement, which is expected to include: a statement of net assets; revenues, expenses and changes in net assets; and cash flows. The balance sheet approach for GI uses two of these sections, namely the statement of net assets and the statement of revenues, expenses and changes in net assets.

In the balance sheet (an example is presented in Table 6.5), the utility's stocks of green assets are broken down and reported by accounting unit (such as rain gardens, forests, or reservoir). This approach is compatible with the UN SEEA and its land cover accounting units. This allows the user to track the 'stock' of assets.

**Table 6.5:** Example balance sheet – stocks of assets

**SOURCE:** Pickle et al. (2014)

| Green asset class | Water supply (Ml) | | Carbon stock (metric tons $CO_2$) | | Land area ($m^2$) | |
|---|---|---|---|---|---|---|
| | Year 1 | Year 2 | Year 1 | Year 2 | Year 1 | Year 2 |
| **Rain gardens** | 1 000 | 900 | 10 000 | 11 000 | 50 000 | 70 000 |
| **Lakes** | 5 000 | 5 200 | 15 000 | 15 000 | 100 000 | 110 000 |
| **Wetlands** | 2 000 | 1 700 | 20 000 | 19 000 | 50 000 | 90 000 |

**Table 6.6:** Example balance sheet – statement of changes in the asset stock

**SOURCE:** Pickle et al. (2014, 3-3)

| Resources | Water stock | Carbon stock | Land area |
|---|---|---|---|
| **Units** | **Kl** | **Metric tons $CO_2$** | **($m^2$)** |
| **Rain garden example** | | | |
| Initial value (last year) | 1 000 | 10 000 | 50 000 |
| Inflows (additions) | 500 | 5 000 | 30 000 |
| Outflows (losses) | 600 | 4 000 | 10 000 |
| Current value (this year) | 900 | 11 000 | 70 000 |

A second statement of changes (Table 6.6) tracks the physical inflows and outflows of resources (e.g. water, carbon, land) that affect the stock of green assets. This is also somewhat aligned with the WRC's work currently being done in South Africa, mentioned previously. Once a baseline of green assets is established, these methods enable the asset to be tracked, and the rate of depletion or growth can be established over time.

Rather than tracking only the assets and the physical units, the ecosystem services approach to GI accounting also converts the asset into the service provided to the relevant utility. This framework tracks a utility's green assets and the specific services each asset provides. It does so by tracking the physical units of infrastructure (e.g. square meters of wetland) or the physical units (e.g. litres of water per year), and the corresponding services that are provided by the green asset (e.g. kilograms of nitrogen removed annually, or water filtration). Determining the physical units is the first step of assessing the overall value of each service.

This model allows utilities to identify assets and ecosystems that are suitable to their specific situation. Particular types of GI (such as forests, wetlands, or rain gardens) are called 'accounting units', with corresponding stocks of material (square meters of forest, number of green roofs, etc.) and services provided. The purpose of the WERF framework is to identify, track and quantify which green assets are relevant to specific utility services; it is not specifically designed to generate a comprehensive green asset registry.

The WERF approach is significant in that it addresses one of the key challenges identified so far, which is how to integrate the GI concept into municipal infrastructure planning and budgeting processes. This approach provides a framework for moving beyond the general recognition of the value provided by existing ecosystem services, to specific and measurable services delivered by clearly delineated or identified assets.

Box 6.2 provides the various steps for implementing an ecosystem services approach within the context of a utility, using the WERF approach.

**BOX 6.2:** Steps to implement an ecosystem services approach within a utility context

**STEP 1: Identify green assets: Are they under the utility control or not?**

**STEP 2: Identify the ecosystem services provided by these assets**
Steps 1 and 2 are illustrated in the table below. Once the green assets are identified, the amount or 'stock' can be determined according to a specific unit (e.g. unit of area – $m^2$). The services provided by these green assets can then be identified and grouped into those services that are operationally relevant to the utility and other services that provide benefits, but that do not accrue to the utility. In the example in the table below, while rain gardens provide a suite of benefits (namely, water infiltration, sediment removal, nitrogen reduction, carbon sequestration and wildlife habitat), only the water infiltration service (and possibly sediment removal) are of interest to a wastewater utility.

| Green assets | | | Ecosystem services – operating | | | Ecosystem services – non-operating | |
|---|---|---|---|---|---|---|---|
| Accounting unit | Physical stock | Units | Water infiltration (l/year) | Sediment removal (kg/year) | Nitrogen reduction (kg/year) | Carbon questration (metric tons $CO_2$/year) | Wildlife habitat (acres) |
| Rain | 567 | $m^2$ | 15 100 | 45 | 7 | 0.1 | 0.1 |
| Swale | 931 | $m^2$ | 22 700 | 70 | 11 | 0.2 | 0.2 |
| Green space | 100 000 | $m^2$ | 75 700 | 410 | 45 | 12.0 | 20.0 |

**STEP 3: Cluster these services into operating and non-operating services**
In this step, the services provided by the particular green asset are unbundled to focus only on the service which is core to the utility's mandate. The remaining services can be grouped as fringe benefits to the municipality or the community in general. The remaining steps focus only on the green assets that are within municipal control and the associated services directly relevant to a particular utility.

| Category | Type of infra-structure | Project or site | Size | Unit | Services provided for utility | Services provided for municipality | Services provided for community |
|---|---|---|---|---|---|---|---|
| Municipal control | Green roofs | Brier Creek | 22 000 | $m^2$ | Reduced runoff | Reduced urban heat island effect | Aesthetic value |

**STEP 4: Define service-based metrics**
Defining service-based metrics is the first step towards assessing the value of the specific service to the utility, in a metric that is known to, and useful for, the utility (see table on the next page).

| Ecosystem service | Potential metrics |
|---|---|
| Reduced runoff | Litres/year OR mm rainfall/year |
| Nutrient removal | Kilograms/year OR year-to-year reduction in nutrient concentration |
| Flood mitigation | Percentage reduction in risk of 10-year flood OR total available flood storage |
| Water storage | Litres |
| Sediment removal | Kilograms/year OR reduction in treatment costs |

**STEP 5: Collect data**

This is the most challenging, costly and time-consuming step. However, once standardised methods are developed (e.g. per $m^2$ estimates of infiltration on certain land types), this will speed up data collection processes. Building on the national asset registry guidelines, the difficulty in quantifying the benefits does not preclude setting up the registry in the first place. Simply identifying and locating the green assets and their associated services is a valuable exercise.

**STEP 6: Present and calculate metrics**

The previous set of steps are combined in this step, which enables the green assets to be aggregated and the service benefits to be quantified (see right-most column of table below).

| Category | Project name | Type | Size | Unit | Services provided | Proposed metrics | Values |
|---|---|---|---|---|---|---|---|
| Municipal control | Brier Creek | Green roofs | 22 000 | $m^2$ | Reduced stormwater runoff | Litres/year | 380 000 |
| Other | Industrial zone | Permeable pavement | 100 000 | $m^2$ | Reduced stormwater runoff | Litres/year | not enough data |
| Direct utility control | Upper Rock Creek | Forests | 600 000 | $m^2$ | Reduced stormwater runoff | Litres/year | 760 000 |
| | | | | | Nutrient removal | Reduction in nutrient | $NO_2$ reduction of 5mg/l |

**STEP 7: Conduct monetary valuation**

With the figures collected in the previous steps, it is a relatively small additional step to place a realistic and robust monetary value on the service provided based on existing service costs for the equivalent unit of infrastructure. This last step was considered by the WERF pilot study to be optional, and none of the participating pilot municipalities chose to do this last step. Nonetheless, this methodology does provide a sound basis for monetary valuation and for developing a cost–benefit analysis comparing GI options against traditional infrastructure options.

**SOURCE:** Adapted from Pickle et al. (2014, 3-3, Appendix B)

## Options for green asset registries in Gauteng

In light of the Gauteng context and the existing regulatory frameworks described thus far, an all-encompassing green asset registry may not be feasible in the short term. However, a simultaneous implementation of a strategic-scale and a project-scale asset registry may be more feasible for including green assets in municipal accounting systems in the short term. These registries would take the form of a comprehensive registry of green assets, either at the GCR or municipal scale, and a utility-based asset registry. This section presents two options for developing green asset registries in Gauteng, drawing strongly on the GI accounting frameworks identified in the previous section.

The first asset registry, a comprehensive registry of green assets either at the GCR or municipal scale, would serve to capture the overall presence, condition and value (in general terms) of ecosystem goods and services provided by a specific green asset, which can provide valuable decision-supporting information at the strategic municipal infrastructure and land use planning levels. The availability of such information at the strategic level would identify the relevant GI and present the opportunity to optimise the use of GI, with instructions given to individual services through the IDP process to investigate the costs and benefits of both green and grey infrastructure options at the pre-feasibility stage. This registry connects strongly with the SEEA framework (described in the section on page 142).

The second registry would be a more conventional utility-based asset registry, used by utilities or specific line departments to track and maintain their service infrastructure, including green assets as these are either adopted by a utility for service purposes, or created (in the case of man-made GI). This registry draws particularly on the WERF approach (described in the section on page 146).

Collectively, these registries could be used to assist with overcoming the economic versus finance dilemma highlighted by Cartwright and Oelofse (2016), which makes it difficult for financial decision-makers to allocate budgets based on economic values. These registries tie into different stages of the municipal planning and budgeting process, as highlighted in Figure 6.2. The comprehensive green asset registry would reflect the total economic value of GI, and help to influence strategic planning decisions which guide the ultimate allocation of resources in municipalities. The utility-based asset registry provides a methodology for generating financial values for a specific class of GI, allowing it to be included in both traditional financial accounts and the budget cycle. This is explained in more detail below.

The comprehensive green asset registry (see '1' in Figure 6.2) provides a decision-supporting tool initially at the IDP level and subsequently to inform the development of service delivery implementation plans. This registry should assist in aligning plans where different departments share mandates, or where ecosystem services transcend line department functions and administrative boundaries.

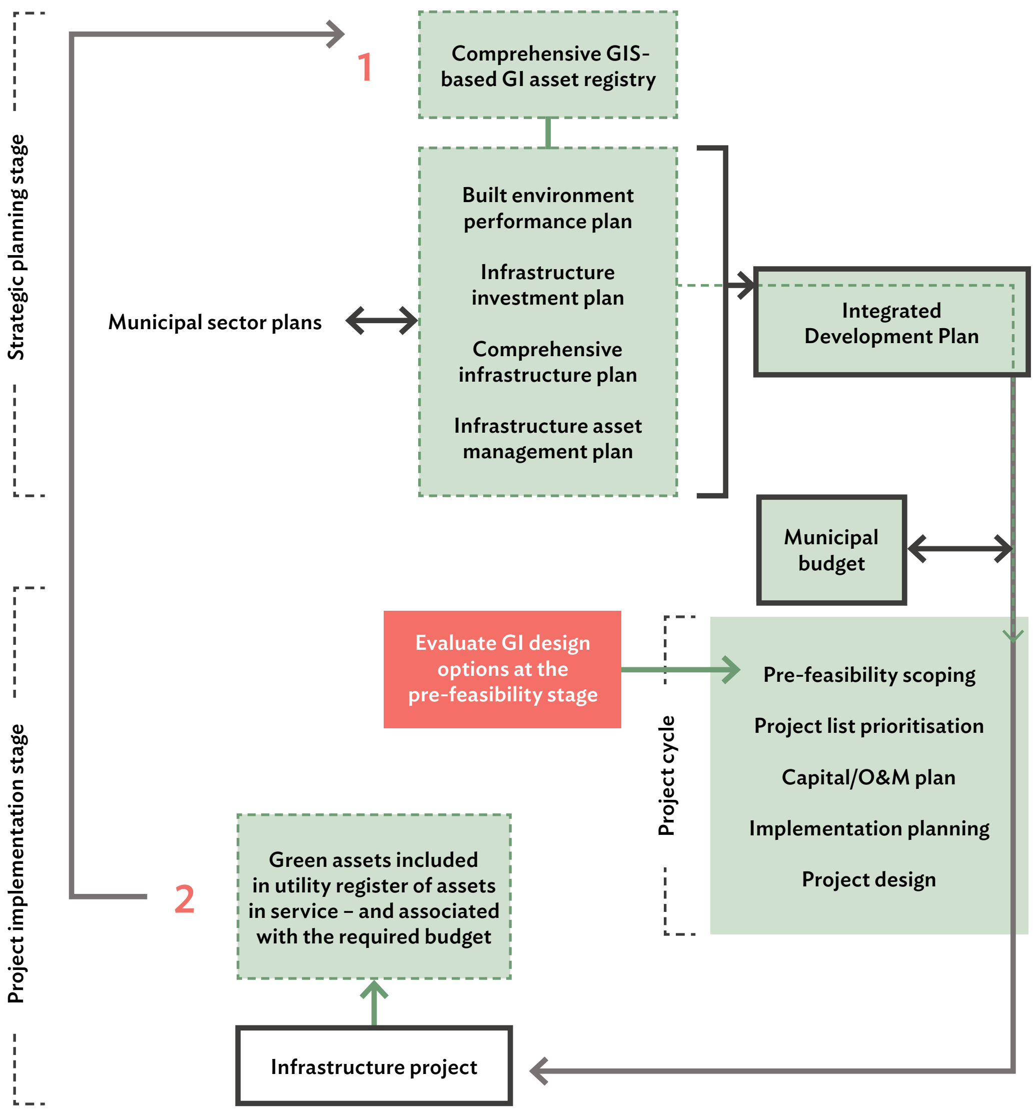
Once a strategic decision has been taken to include specific ecosystem services, the relevant departments are tasked, through the IDP, with properly evaluating both grey and green design options at the pre-feasibility stage. This should be required whether or not the pre-feasibility study is conducted in-house or by outside consultants.[11] If green assets meet the technical service requirements and prove to be the best option for a particular project, the project should proceed as normal, and the green asset (incorporated or generated) can be included in the utility-based asset registry (see '2' in Figure 6.2), which is linked to the required budget funds.

As the detail regarding the performance of green assets is developed over time through the utility-based asset registry, this should refine and improve the comprehensive asset registry.

11 Consultants are often reluctant to implement new and potentially risky (in their view) options to minimise their own financial risk. This is why they have to be specifically instructed to evaluate and compare green and grey options at the very beginning of the project cycle.

**Figure 6.2:** Suggested asset registries in the context of municipal infrastructure planning processes

**SOURCE:** Author, informed by the Municipal Infrastructure: Roles and Responsibilities booklet (DPLG, n.d.) as well as DBSA (2011)




*Both green and grey design options should be evaluated at the pre-feasibility stage*

## Comprehensive green asset registry

The strategic-scale registry consists of a comprehensive GIS-based asset registry covering an entire municipality or the GCR. If there is alignment between the accounting frameworks at the municipal and provincial scales, it is possible to use the same green asset registry for the entire region to support GCR-, provincial- or municipal-level infrastructure planning. Municipalities could then extract the data for their own jurisdiction to inform municipal-level planning, taking into account regional environmental considerations.

If this asset registry is built to be compatible with the international SEEA and related StatsSA reporting frameworks, this will allow for richer reporting and analysis over the longer term in addition to avoiding any confusion which may be created by the presence of different environmental accounting frameworks. StatsSA is currently working on adapting the SEEA framework to the South African context, which will provide GCR municipalities with invaluable insights in applying the SEEA framework locally.

It is at the level of integrated municipal infrastructure planning that a GIS-based green asset registry should ultimately be employed to identify how green assets and ecosystem services can be used to support the municipal needs identified through the IDP process and, from there, result in specific IDP projects.

In addition, the green asset registry should inform land use planning decisions on an ongoing basis, to avoid the loss or degradation of key green assets. The Spatial Planning and Land Use Management Act (SPLUMA, No. 16 of 2013) requires that all municipalities prepare a Spatial Development Framework (SDF), which must include a strategic environmental assessment of the pressures and opportunities within the municipal area, including, where applicable, the spatial location of environmental sensitivities, high potential agricultural land and coastal access strips.[12] This assessment could refer or link to the comprehensive green asset registry, and help to track the current stock of green assets.

It is important that this registry be maintained and updated on a regular basis.

It is anticipated that a comprehensive green asset registry will be costly and time-consuming to construct, so it should build on the work already undertaken by various GCR municipalities, the GCRO's *State of green infrastructure in the Gauteng City-Region* report (Schäffler et al., 2013), or through collaboration with partners such as StatsSA and the NSIF to reduce the data-gathering burden, and also to standardise data-gathering and management practices. If the registry is coupled to the SDF and strategic environmental assessment processes, this could reduce the work required to develop the database. The Gauteng Planning Department could play a key role in this process. The green asset registry can be continually enhanced and refined as more case-study evidence becomes available.

A comprehensive green asset registry can help to provide a common understanding of what GI is and what its benefits to the municipality are, and may accelerate the uptake of GI projects (Dunsmore, 2016). The development of the comprehensive registry can also serve to address the problem of unfamiliarity identified by Cartwright and Oelofse (2016), where many municipal officials were unaware of the notion that a wetland could be used to provide flood retention or water purification. In this way, the green asset registry can be used to guide infrastructure decisions at a strategic level, without the need for detailed and costly valuation methods.

The registry database can be populated fairly rapidly using existing digital spatial data on green assets (collected by provincial and municipal government, and other institutions such as SANBI) to provide base land cover/ecosystem type information. This process will help identify what and where the green assets are, and the services they provide. This information would then be mapped, and form the basis of a first draft municipal-level comprehensive green asset registry. It is important that this not be housed in departments such as Parks and Recreation, but rather within whichever municipal unit is responsible for strategic-level planning.

12 Section 21(j) of SPLUMA. A similar provision is contained in section 2(4)(f) of the Local Government: Municipal Planning and Performance Management Regulations.

It is important to note that this approach is dependent on detailed land cover maps at the local scale which are based on informed cadastral boundaries and ownership rather than derived from satellite imagery. This poses a significant challenge as such data are lacking in many municipalities.

### Utility-level asset registry

The second type of asset registry provides a mechanism for incorporating specific green assets into utility-level service asset registries, which are governed by existing GRAP accounting rules (see the section on page 131). It is only once green assets are recognised as 'assets in service' that budget will be allocated for maintaining specific green assets.

Once the role of ecosystem services in supporting traditional grey assets has been identified at the strategic level of IDPs or other statutory planning processes, sector departments should then ideally be tasked with conducting pre-feasibility cost–benefit evaluations of both green and grey infrastructure to meet the specified social or service need (see an example of this in Chapter 5).

Once more evidence becomes available about the performance of GI on equivalent service-based metrics as shown in the WERF pilot (and rather than on estimates of economic value, which are incomparable at a service level), and utility officials are convinced of the efficacy of GI solutions, it will become easier to integrate green and grey infrastructure solutions.

Green assets which can be quantified and measured in the way discussed under the WERF framework will also be more likely to pass the accounting recognition tests, and be included into formal service asset accounting. This, in turn, will enable the allocation of sufficient budgets for required maintenance expenditure.

The success of using a service-based approach in quantifying ecosystem services has been proven in cases such as the New York Green Infrastructure Plan (see Box 6.3).[13] This approach did not start from a broad premise of valuing all ecosystem services, but rather with a specific problem faced by the municipality. This approach, together with the IDP, shows the most promise in the GCR in terms of potential for promoting the use of GI as part of infrastructure networks.

**Box 6.3:** Addressing a service-based problem in New York City through green infrastructure

The New York Green Infrastructure plan (NYC Environmental Protection, 2010) arose from the problem of how to manage the larger volumes of stormwater and more stringent effluent quality regulations. The plan is the result of a cost–benefit analysis that the City undertook to assess options for improving the water quality released from the City's combined stormwater and sewerage system. The relevant agency compared a combined grey-green infrastructure solution with a traditional grey infrastructure option in terms of their respective abilities to address the problem. The performance was measured against both financial cost and utility-related metrics. This enabled the utility to see that with the grey-green option, not only were their budgets better off, but the GI elements also reduced the volumes of stormwater that entered the system and required purification (see also Bobbins, 2016).

13 See https://www1.nyc.gov/site/dep/water/green-infrastructure.page for a link to all plans and reports.

## Conclusion

The overarching goal of a green asset registry is to maximise the opportunities for GI to be planned together with traditional grey infrastructure. This chapter has described the conventional asset planning management and accounting frameworks in South Africa as well as some existing frameworks for developing green asset registries. Based on these various frameworks, two options for incorporating green assets into conventional accounting systems were proposed: a comprehensive green asset registry and a utility-level asset registry.

This chapter has demonstrated the complexity and time-consuming nature of developing an asset registry, and thus it would be advisable that the green asset registry be developed incrementally based on the framework set out by the National Treasury (2008a). The green asset registry could be compiled in stages with each stage adding additional detail (such as location, custodian and condition) as this information becomes available. There is a range of existing information sources and work being done in this field which can be drawn upon. This will reduce the burden of developing new datasets, and will not only speed up the process, but also reduce duplicated effort.

A key component of a green asset registry is that the GI is associated with services relevant to municipal departments. In developing a green asset registry, it will be critical to engage utility-level officials in identifying green assets which can meet their service delivery needs. In cases where municipal officials are unfamiliar with GI, or sceptical of their usefulness, it is particularly important to have pilot projects and cost–benefit analyses to demonstrate the potential of GI for addressing the service delivery mandates.

The ability of a single green asset to provide a variety of different services that can be relevant for a number of different utilities is a major benefit of GI compared to traditional grey infrastructure. While this has implications for coordination across departments and/or utilities, the multiplicity of services provides an opportunity for the municipality to benefit in multiple ways from investing and maintaining a single green asset. This characteristic of GI also links strongly with urban resilience (Bobbins & Culwick, 2015).

Although recently published good practice guidelines for municipal infrastructure management do not include concepts like GI, they do highlight the importance of infrastructure resilience. Adopting GI's framing around resilience allows it to be inserted into the conversation about how to adapt to changing climate conditions due to global warming. It would

Photograph by Mazolo Dube

be possible to use the proposed comprehensive or strategic-scale green asset registry to advance agendas and solve related problems. This will require that GI is integrated into core municipal statutory plans including IDPs and SDFs, which could be achieved through the use of a green asset registry.

A comprehensive green asset registry is particularly important where ecosystem services transcend line department functions and administrative boundaries, and where single green assets provide a range of services relevant to a number of utilities or departments. It is necessary that this comprehensive registry is developed using a spatial GIS platform, which can inform decision-making at the overall municipal infrastructure planning level as well as the departmental level. In this chapter, it has been proposed that a strategic- and project-level registry be developed simultaneously. Ensuring that green assets are translated into the relevant accounting and planning terms will increase their likelihood of being included in strategic plans and as potential alternatives at the project scale. While some work has been conducted into identifying how green assets can be incorporated into government accounting and management systems, further work is still required in both the unbundling of green assets into different asset classes, and in identifying how these green assets should be accounted for.

This chapter has emphasised the importance of targeting the municipal engineer and piggybacking on existing asset management support initiatives. Municipal engineers are central to compliance with, and use of, asset registries. Thus, mainstreaming GI into strategic- and project-level planning requires the buy-in of municipal engineers. The Institute of Municipal Engineering in South Africa is a key source of information for municipal engineers with regard to asset management best practice. Asset management and maintenance in South Africa is poor at present, and this might be an opportunity to ensure that, as effort is put into improving current asset registries, green assets begin to be included. This will also be aided by the development of pilot studies and cost–benefit analyses that demonstrate the functioning, cost and benefits of GI options.

Incorporating green assets into conventional asset registries is a critical step in supporting a widespread uptake of a GI approach, and this chapter has contributed to a better understanding of how this might be possible in the GCR.

Photograph by Susan Snaddon

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**GAUTENG CITY-REGION OBSERVATORY**

6th Floor University Corner
11 Jorissen St (Cnr Jorissen and Jan Smuts)
Braamfontein
Johannesburg
Gauteng, South Africa

tel +27 11 717 7280
email info@gcro.ac.za
www.gcro.ac.za