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Exploring Multi-functional Blue-green Infrastructure: Re-designing Stormwater Ponds Over the Cape Flats Aquifer

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Exploring Multi-functional Blue-green Infrastructure: Re-designing Stormwater Ponds Over the Cape Flats Aquifer

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31 May 2022
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Acknowledgments

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Abstract

Water-sensitive urban design is becoming increasingly important for urban water security and climate adaptation, especially as drought becomes more frequent and intense in semi-arid countries like South Africa. There is therefore more interest in multi-functional blue-green infrastructure, given its integration of urban water resource management, ecological services, as well as social amenity into one space. This paper explored the use of native Western Cape vegetation in the Rondevlei Park Pond in Rondevlei, Mitchells Plain to support multi-functionality. Based on literature, more than half of the native plants identified at the Pond provided at least one ecological service that attributes to one of the aforementioned multi-BGI components. Five of the native species are effective phytoremediators of 21 different contaminants ranging from anthropogenic chemicals to heavy metals. Moreover, all five species combined are able to remove Cape Town contaminants of emerging concern. Further research can be done in Cape Town to understand the use of native Western Cape plant species in BGI and ecosystem rehabilitation. For example, aside from studies on root structure in phytoremediation, there was limited information on the relationship between native plant root structure and soil porosity, or any other plant characteristics that might influence the quantity of stormwater infiltration.
Introduction

South Africa is the 30th driest country in the world, with rainfall averaging less than 500 mm/year. The country’s overall climate is semi-arid characterized by rainfall that is unevenly distributed in space and time. The City of Cape Town (CoCT) is a coastal city with a Mediterranean-like climate. It is located in the Western Cape (WC) Province and is heavily dependent on winter rainfall (Madonsela et al. 2018). Since 1996, the city’s population has increased by 56%, which has placed further strain on its water supply. In the recent 2017-18 drought in the WC, a decline in winter rains started in 2016 and led to the total volume of Cape Town’s water supplies falling below 30% (Mauck and Winter 2021).

Under the context of climate change and growing concern for a drier climate, the crisis highlighted the need for the city to understand the existing vulnerabilities of its current water supply system and to diversify its sources of water to include treated wastewater, stormwater, and desalination (Mauck and Winter 2021; Nyam 2020). The Cape Town Water Strategy lists five commitments: safe access to water and sanitation; wise use; sufficient, reliable water from diverse sources; shared benefits from regional water resources; and a water-sensitive city (CoCT). Currently, around 94% of Cape Town’s water is supplied from six major surface-water dams outside the city and the remaining 6% is largely obtained by groundwater abstraction (Mauck and Winter 2021; Gobin et al. 2018). The Cape Flats Aquifer (CFA) has been explored as an alternative freshwater resource and has been shown to have the largest potential for managed aquifer recharge (MAR), and thus possibilities for sustainable groundwater extraction, in Mitchells Plain and Philippi, as shown in Figure 1 (Adelana and Xu 2006; Mauck and Winter 2021). Developing the framework and technology to utilize this resource may directly address part of the CoCT commitments, especially sufficient, reliable water from diverse sources and a water-sensitive city.
MAR is achieved through injection or infiltration or stormwater. Stormwater management has therefore become even more relevant to water resource management in water-scarce cities like Cape Town. The CoCT enacted numerous policies governing stormwater management and disposal in the city. Such policies include the CoCT Stormwater Management Bylaw, the Management of Urban Stormwater Impacts Policy, and the Floodplain and River Management Policy. Together, these policies are intended to encourage sustainable development, as well as, a balanced consideration of potential environmental impacts, flood risk, and socio-economic needs. (Robertson 2017)

Therefore, to achieve these goals of better awareness around stormwater management and its impacts, the Management of Urban Stormwater Impacts Policy promotes the use of Water Sensitive Design principles in the City’s stormwater management. The policy outlines the City’s objectives to improve the quality of stormwater runoff, control the quantity and rate of stormwater runoff, and encourage natural groundwater recharge. All developments in Cape Town are required to collect litter, oil, and grease in stormwater at the source. The policy also requires
that the annual load of total suspended solids (TSS) and total phosphorus (TP) be reduced by 80% and 45%, respectively, in stormwater from all developments. (Robertson 2017)

Traditional stormwater infrastructure and practices focus on managing stormwater quantity. Their primary function is to quickly re-direct stormwater flows, channeling stormwater through drainage networks to receiving waters. This is usually with little regard for either short- or long-term environmental impacts. This results in ecotoxicity in and outside urban environments due to stormwater pollution, as well as, erosion, siltation, pollution, and limited infiltration and groundwater recharge. (Robertson 2017)

Figure 2: The Rondevlei Park Pond, Rondevlei, Mitchells Plain

Much attention has been turned to Sustainable Drainage Systems (SuDS) to achieve a more holistic and multi-purpose framework for stormwater drainage management. SuDS is an umbrella term to describe drainage systems that direct surface drainage and improve water quality (Robertson 2017). Pathways to Water-Sensitive South African Cities (PaWS) is an initiative under the University of Cape Town’s Future Water Insititute to adapt existing,
well-establish flood-control infrastructure with nature-based solutions, including green infrastructure and water-sensitive design, to explore the potential to harvest stormwater to recharge the CFA. The goal of the project is to facilitate the physical and institutional integration of stormwater ponds as decentralized water sources to accelerate the transition towards water resilience in South African cities like Cape Town (Future Water).

Figure 3: Location of RPP in Rondevlei, Mitchells Plain

The PaWS project selected a stormwater pond in Rondevlei, Mitchells Plain as the primary site for investigations due to safety and its ideal design. The pond’s inlets and outlet are opposite each other and Future Water had expected sand to be the main soil component which would maximize ground infiltration. The Rondevlei Park Pond (RPP) is situated in a residential area, and similar to most other stormwater ponds, it is currently monofunctional. Stormwater ponds are traditionally made to collect stormwater in areas with a high proportion of impervious surfaces, including roads and sidewalks that make ground infiltration difficult, and for this runoff
into the pond to be piped from the pond outlet to a receiving body of water (such as a river or ocean) (Jacklin et al. Aug 2021). This process is illustrated in Figure 4.

![Figure 4: Diagram showing the function of traditional stormwater pond](image)

PaWS is finding ways to infiltrate and harvest as much of this stormwater into the CFA below the stormwater ponds before it evaporates or drains away. Based on interviews previously gathered with residents of the neighborhood surrounding the pond, the RPP could also be more multi-functional to support community life by incorporating interactive green spaces for relaxing and recreational activities.

To support the PaWS project in integrating nature-based solutions in the existing stormwater infrastructure, this project will investigate how species of native vegetation can be used in the pond to support its multi-functionality. Potential benefits of re-introducing or improving systems of native vegetation might include phytoremediation of stormwater going into the pond, better infiltration of stormwater into the CFA, more greenery aesthetics in the neighborhood, as well as opportunities for educating residents about the value of such ecological services provided by native vegetation. Therefore, native vegetation may improve the CFA water quality and quantity under the RPP and provide green space and recreational facilities for the surrounding neighborhood (Jacklin et al. Jul 2021; Jacklin et al. Aug 2021; Hua et al. 2014; Willemse 2017).
My research question is thus: How can stormwater ponds over the Cape Flats Aquifer be re-designed to use multi-functional blue-green infrastructure?

“Multi-functional blue-green infrastructure” (multi-BGI) is used over the term “green infrastructure,” as it better encaptures my goals to integrate land use planning and water resource management, as well as my desired emphasis on the sustainability and resiliency of the ecosystems introduced in re-designing the RPP (Yang and Dobbie 2018, Lähde et al. 2019, Stovin and Ashley 2019).

Rationale

Water-sensitive urban design is becoming increasingly important for urban water security and climate adaptation, especially as drought becomes more frequent and intense in semi-arid countries like South Africa (Yang and Dobbie 2018, Lähde et al. 2019). To achieve CoCT commitments and goals for sustainable water resource management, urban infrastructure needs to be more flexible and holistic. This has resulted in the developing interest in SuDS and green infrastructure which integrate sustainable land and water management to build urban resilience and ecological health. There is also greater interest in the ecological services—the benefits people obtain from ecosystems—green infrastructure can provide in urban spaces (Yang and Dobbie 2018).

Multi-functionality has become a new ideal, where engineers and architects explore the idea of infrastructure and spaces offering multiple services in one place. This multi-functionality can be defined as one space providing many ecological services or having integrated and interacting functions. In this study, multi-BGI will take on the definition of BGI that offers multiple ecological services and will be based on the framework used by Lähde et al. 2019. This entails infrastructure that is designed for water management (quantity and quality), biodiversity, and social amenity.

There is evidence that plant biofiltration, a form of BGI technology, can support the function of stormwater infrastructure by removing common pollutants in stormwater, facilitating infiltration, and reducing high levels of nitrogen (Jacklin et al. Jul 2021; Jacklin et al. Aug 2021; Hua et al.). While there is a wide range of vegetation that can offer such services, South Africa has a long history of biological invasions, which have altered the structure and function of its natural ecosystems. This transformation of native ecosystems has threatened their capacity to
deliver ecological goods and services. This is especially evident in the WC Province, where fynbos ecosystems have lost over 195 billion ZAR of their value in ecosystem services (Jacklin et al. Aug 2021). Therefore, this study will prioritize the use of indigenous vegetation, as the ecology of urban spaces like Cape Town is often already compromised by invasive species and non-indigenous vegetation (Goodness and Anderson 2020, Jacklin et al. Aug 2021).

Research on native phytoremediators, which are plants that are able to remove contaminants from water and soil, is quite promising. After investigating 800 literature sources, Jacklin et al. (Jul 2021) identified 56 non-invasive species that are endemic or indigenous to the WC Province for potential use in phytoremediation within BGI initiatives. The 56 species gathered are also considered to be of least conservation concern, likely implying that they are quite robust and not being threatened by urbanization, environmental degradation, or other contemporary threats. The authors suggest that such aggressive growth properties are ideal characteristics among the most efficient and long-lasting remediating species. However, engineers designing BGI must still be cautious of even the “non-invasive” species listed and need to thoroughly consider the site context for BGI. This might include assessing the targeted on-site pollutants as well as the various factors that contribute to a dynamic and resilient ecosystem, including inter-species interactions and rhizospheric fluctuations due to pollutant deposition and accumulation (Jacklin et al. Jul 2021).

*Juncus effusus* is an example of a robust native species that is suitable for sustainable urban remediation. In an experiment comparing the remediation of stormwater effluent from unvegetated cells and vegetated cells with the indigenous species *J. effusus* and different soil mixes, Jacklin et al. (Aug 2021) found that vegetated cells were better able to remove metals in stormwater, including copper, lead, and zinc. Higher rates of removal by *J. effusus* were mainly attributed to filtration and adsorption methods. The study found that plants can directly uptake metals and other nutrient pollution in stormwater as fertilizer, such that pollution in stormwater can actually support plant development and growth. Overall, the experiment showed that compared to unvegetated biofilters, vegetated systems are significantly better equipped to sustain infiltration during a large influx of precipitation and thus large amounts of stormwater runoff. There were also no effects observed on the plant growth rate of *J. effusus* due to nutrient or metal toxicity. (Jacklin et al. Aug 2021)
Aside from the potential to support the filtration of polluted stormwater, Hua et al. suggest plants can also benefit BGI by making soil or other growing media more porous. In the upper layer of soil (0-30 cm), plant roots are most concentrated and add pore channels that prevent sand compaction and support the soil in maintaining greater porosity overall (Hua et al. 2014). In the context of the RPP, intentionally incorporating vegetation into the pond’s design may allow for more stormwater to infiltrate the ground and thus help to recharge the CFA.

Finally, Willemse (2017) interviewed residents in five different neighborhoods of Mitchells Plain, one of these neighboring the RPP area. Their study emphasizes that parks and green spaces provide functional, aesthetic, and ecological attributes and could encourage sustainable lifestyles in low-income neighborhoods in Cape Town, which historically lack access to such spaces due to Apartheid planning. Between all five neighborhoods, most residents expressed the need for well-maintained and safe green spaces with opportunities for children to participate in active recreational activities and for adults to relax. Zero to five percent of participants preferred paved recreational spaces (Willemse 2017). There is therefore much support from the local community for ensuring the RPP is designed as a green space. Further, prioritizing the pond design around incorporating more native vegetation will simultaneously provide filtration and infiltration services to improve the function of the stormwater pond infrastructure as well as serve the surrounding community by offering green space with opportunities for recreation.

Overall, the relevant literature supports that plant biofiltration can be an important contribution to blue-green infrastructure, offering many benefits for urban water protection and managed aquifer recharge. However, it also suggests that there is a possible lack of literature investigating the potential of WC plant species for BGI (Jacklin et al. Jul 2021). The field also stresses the need to adopt a broader perspective around blue-green infrastructure, where engineers move away from monofunctional infrastructure and incorporate a cross-disciplinary understanding of the landscape including both ecological and social benefits into their design (Stovin and Ashley; Jacklin et al. Jul 2021; Willemse).

To address these gaps, the focus of this project is to design blue-green infrastructure that uses native WC plant species to provide ecological services for the benefit of the stormwater pond function and the aesthetics and leisure of the surrounding community. The pond design generated will also realize the fact that building a plant community with ecological resilience and
sustainability in mind may ensure the plant species chosen will offer optimized benefits and services. Therefore, with an emphasis on long-term sustainability, this study will modify the ecological component of the Lähde framework to be ecological sustainability and resilience. This is more appropriate as the study is already considering the biodiversity of native vegetation, and places further emphasis on the need for multi-BGI as a form of long-term climate adaption and resilience needed in urban environments.

**Methods**

According to Robertson 2017, the treatment capacity of SuDS depends on environmental factors such as topography, local climate, soil type, and plant species characteristics. This paper is focused on understanding the use of native vegetation in the RPP to support multi-functionality. Therefore, the following methods are to study plant species characteristics and their value to BGI.

*Vegetation Survey of RPP*

![Vegetation Survey of RPP](image)

Figure 5: Diagram of the Survey Area at the RPP
A survey of the plant species at the Rondvlei Park Pond was conducted to understand the current ecology of the pond and the types of vegetation there. Samples of plant species were collected in the section of the pond between the outlet and inlet, as marked in Figure 5 below. Multiple samples of the same species were useful to identify plants that have more distinct features at certain stages in their growth cycle. For example, one sample of a species may demonstrate its stem traits while another may have fully developed flowers.

Furthermore, the pond vegetation is not being maintained and grows very thick, so, collecting shorter vegetation closer to the ground was quite difficult. Therefore, this survey may have been biased toward the vegetation most easily visible. This survey is also limited to plants in season during March and April.

Another limitation is not having an ecologist present on-site during collection who was more familiar with the local vegetation. For the above reasons, the purpose of this survey was to gather a general sense of the indigenous and non-indigenous vegetation currently present on site. A more detailed survey, over a longer period of time, would have been ideal, but not possible due to time constraints.

*Exploring Cape Flats Wetland Ecology*

![Exploring Cape Flats Wetland Ecology](image)

*Figure 6: Wolfgat Nature Reserve (Source: Wikipedia)*
The plants collected from the pond site were identified to a species level if possible. Whether they were indigenous was determined using a catalog of species common in the Cape Flats Strandveld Dune Area from sources like iNaturalist and Communitree. Literature was then compiled on the indigenous vegetation found to study the ecological services that those species might provide for the ecology of the pond and to support its function in the stormwater infrastructure (phytoremediation, filtration, etc). The lab experiments reviewed were mostly isolated tests. Therefore, the combined effect of the vegetation that would realistically occur at the Pond could not be explored due to time constraints on conducting experiments.

The study also explored other indigenous species that might be added to contribute to the site's blue-green infrastructure and ecological resilience. To identify such key native plant species in such wetland environments, the Wolfgat Reserve was used as an example of ongoing rehabilitation and conservation projects of wetland ecosystems in the Cape Flats Sand Dune region which are also close to the RPP. The preferred location of native vegetation in the pond ecosystem was also studied for the optimal provision of ecological services.

Proposal for Pond Design

Figure 7: Pond 3D design rendering and contour lines

This review of literature generated a list of native plant species that support the RPP's ecological health and the recharge of the CFA. These methods not only worked towards
understanding how the site can provide ecological services but also found how this pond can serve as blue-green infrastructure that supports the Rondevlei community in social aspects as well. The PaWS project had already collaborated with Rondevlei residents to gather concerns and expectations for future outcomes of the pond. Willemse (2017) also gives insights into the general need for more green spaces in Mitchells Plain in his analysis of interviews with residents of 5 neighborhoods in Mitchell’s Plain, including one next to Rondevlei.

To build this research as a blueprint for a multi-functional pond design, a 3D model of the RPP re-designed as blue-green infrastructure was generated to accommodate the community, the functioning of the stormwater pond as a site for aquifer recharge, as well as its ecological resilience.

Further limitations include the unknowns of site characteristics, including stormwater contaminants, soil quality and type distribution, as well as the distribution of water infiltration at the Pond. Soil types are generally known to include sand, clay, and limestone, although their distribution throughout the Pond is not certain.

**Results & Discussion**

*Plant Identification*

33 plant species were collected at the RPP site in Mitchells Plain. 22 species were identified—15 being indigenous to the WC and seven that were introduced. The 11 unknown species were either not flowering at the time of collection, making them difficult to identify with a dichotomous key, or were not found in the Seek iNaturalist database. Refer to Appendix A for pictures of the plant species collected, as well as their names if identified.

The 15 indigenous species and their benefits to BGI in Cape Town were categorized with respect to the multi-functional framework. Out of the 15 indigenous plant species, published literature shows evidence for five being effective phytoremediators with the ability to improve water quality, three of which might also provide ecological benefits. Further, literature was found for another three out of the 15 species supporting their possible social benefits, including potential for medicinal uses.
Stormwater Quality in Cape Town

To understand the potential for the five native phytoremediators to remove the pollutants most relevant to the RPP site, stormwater from Rondelveli Park, Mitchells Plain would need to be sampled and tested for the prominent contaminants, especially those of most concern for human and environmental health. Future Water has sampled the groundwater from the four monitoring wells located throughout the pond, shown in Figure 8, to test for the concentrations of nutrients, including nitrate and orthophosphate, and will soon get results about levels of contaminants of emerging concern (CECs), such as heavy metals. The results so far can be found in Appendix B. There were no concerning levels of pollution, however, these tests were not sensitive to trace amounts of CECs and were limited to the groundwater around the wellpoints. Therefore, what is currently known about the water quality at the RPP is only relevant to levels of nutrient contamination in the groundwater below the pond, and even so, might not reflect the quality of the groundwater throughout the pond as factors such as soil type and depth change.
The quality of stormwater going into the pond is unknown and there was no literature for studies on the stormwater in Rondevlei Park or Mitchells Plain more generally. This makes it difficult to understand which phytoremediators are most useful at the RPP and suggests the need for more research and data to be collected on the stormwater quality in Mitchells Plain.

There are, however, studies of stormwater quality in Cape Town, with a large focus on the discharge into the Liesbeek River. These studies identified some of the predominant CECs polluting stormwater in Cape Town and were used as a reference for the CECs likely to be present in the stormwater entering the Pond in Rondevlei.
Robertson 2017 conducted a study along the R300 highway to assess the pollutants in stormwater coming off highways in Cape Town. While R300 passes just two kilometers north of the Pond (Figure 10), all four of the study’s runoff sampling sites (Figure 11) were along R300 between the N1 and N2, which is right before the highway passes through Mitchell’s Plain. This study, therefore, may not be appropriate to represent stormwater pollution in Mitchell’s Plain but still helps to understand stormwater pollution near the Mitchell’s Plain area and around Cape Town in general. Other limitations may be found in the study itself, since stormwater runoff has a heterogenous mix of rainfall, sewage, and contaminants but was sampled in the study as small fractions of the incoming flow. These samples therefore cannot account for the high variability in runoff quality and are thus unlikely to be fully representative of CEC concentration and distribution along R300.
The study compared the contaminant concentrations determined at the four sites to guidelines provided by the South African government for maximum contaminant levels to ensure the health of waterways and aquatic ecosystems. The Department of Environmental Affairs (DEA) has regulations for the oil and grease concentration of discharge into river catchments, allowing up to 2.5 mg/l (Robertson 2017). Between the four sites, the study found a mean concentration of 144 mg/l for oil and grease in the highway runoff, which clearly exceeds the DEA effluent standards. Furthermore, the study refers to the upper limits of the Target Water Quality Range (TWQR) and the Acute Effect Value (AEV) set by the Department of Water and Sanitation (DWS). The TWQR gives a range of concentrations of pollutants that present no harmful effects on ecosystem health. The AEV represents a concentration above which up to 5% of aquatic species will be affected by ecotoxicity, such that if levels beyond this point of toxicity
are maintained, sensitive species will be endangered. Robertson found the mean concentration of aluminum, copper, lead, phosphorus, and zinc had all exceeded the AEV by 1000%, indicating concerning levels of these CECs that are polluting Cape Town’s waterways and eventually those receiving this stormwater discharge. (Robertson 2017)

Robertson 2007 concluded that when comparing highway runoff concentrations to DEA and DWS water quality standards for aquatic ecosystems, the primary contaminants along R300 were aluminum, copper, lead, phosphorus, zinc, TSS, oil, and grease.

![Figure 12: Drainage catch pits (Source: Ward 2014)](image)

Other literature studied stormwater quality in residential areas of Cape Town. Ward 2014 monitored the stormwater quality in 25 selected drainage catch pits—13 in Newlands and 12 in Observatory (Figure 12)—along the Liesbeek River catchment. The stormwater was sampled
from the sites after 24 storm events over a five-month period during the winter season and tested for nutrient contamination. Ward found that concentrations of orthophosphate, nitrate, and nitrite exceeded limits set in the 1999 National Water Act. The pH range observed in the study area was also outside of the lower and upper limits.

While this study is further from the RPP in Mitchells Plain compared to Robertson 2017, Ward’s findings may suggest that nutrient levels in the stormwater runoff coming from residential areas in Cape Town are likely higher than government standards. Ward also analyzed residents’ understanding of stormwater infrastructure and drainage, as well as their perception of their role in urban stormwater pollution. The study found that such high levels of nutrient pollution may be attributed to residents’ lack of awareness around their impact on stormwater quality, especially regarding certain behavior such as regular use of fertilizer or drainage of wastewater into stormwater drains, which is against regulations. Ward suggests that this lack of awareness around regulation and the resulting impact of resident behavior on urban water quality may produce similar patterns in high nutrient levels in stormwater in other residential areas of Cape Town, including Rondevlei Park. The study, however, only focuses on nutrient pollution in residential stormwater and thus gives little indication of the CECs that may be common in Cape Town’s residential areas.

Based on these two studies, one representing residential areas in Cape Town and the other studying stormwater closer to Mitchells Plain, the CECs in Cape Town’s stormwater may be summarized as the following: aluminum, copper, lead, phosphorus, zinc, TSS, oil, grease, orthophosphate, nitrate, and nitrite (Robertson 2017; Ward 2014). Due to their prevalence in various areas of Cape Town, these may be expected in the stormwater that drains into the RPP.

*Water Management—Quality*

There are two main types of phytoremediation. Phytoextraction is when plants have the ability to accumulate high concentrations of pollutants, including metals, in their shoot tissue. Another method of phytoremediation is phytostabilization, where plants immobilize or stabilize contaminants in the soil, preventing or delaying leaching into groundwater or runoff (Schachtschneider et al. 2017). Appendix C lists the five indigenous phytoremediators identified at the Pond—*Cyperus rotundus, Schoenoplectus corymbosus, Phragmites australis, Typha capensis, and Paspalum vaginatum Sw.*—and the pollutants they have the potential to remove.
from water based on literature. In bold are the CECs most common in Cape Town according to Robertson 2017 and Ward 2014. All five of the plant species have the potential to remove these CECs, some capable of removing six of the eleven identified.

*Cyperus rotundus*, Purple Nutsedge

*Cyperus rotundus*, or the Purple Nutsedge, is an indigenous plant species currently at the Pond site. It is common throughout South Africa and prefers wet environments (N.C. Extension, KZN Department of Agriculture and Rural Development). *C. rotundus* is an effective phytoremediator of PHC, one of the CECs found in Cape Town’s stormwater (Robertson 2017; Basumatary et al. 2013). In an experiment studying *C. rotundus* and *Cyperus brevifolius* in sites contaminated with petroleum hydrocarbon (PHC) sludge, both species were found to be able to survive in soils with up to 10% PHC contamination. However, compared to *C. brevifolius*, *C. rotundus* columns showed over 10% more total petroleum hydrocarbon (TPH) degradation, removing 75% of TPH over a 360-day period. The TPH removal in unvegetated soil was as much as 12% in 360 days, likely driven by microbial degradation. These results show that vegetated columns, especially those with *C. rotundus* are much more effective at removing PHC from contaminated soils. The plant has an extensive fibrous root system, creating a large surface area favorable for phytoremediation. This is supported by the observation of a correlation between total root length and TPH degradation on a 5% significance level. (Basumatary et al. 2013)
A concern for using *C. rotundus* for phytoremediation might be the potential for accumulation of PHC in the plant tissues, as more TPH was found to accumulate in plant shoots than in roots ($p < 0.05$) (Basumatary et al. 2013). Furthermore, this PHC remediation study was conducted in Assam, India. A study performed in similar climatic conditions and soil characteristics might be helpful to understand the potential of *C. rotundus* in Cape Town BGI.

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*Paspalum vaginatum Sw.*, Seashore Paspalum

*Paspalum vaginatum Sw.* (Seashore Paspalum) is a warm-season, salt-tolerant turfgrass. Like *C. rotundus*, studies suggest *P. vaginatum Sw.* may also be used for the rehabilitation of oil-contaminated sites. The plant's ecological services include reducing soil erosion, accelerating hydrocarbon degradation by generating a more aerobic soil environment, and enhancing habitat restoration. One major challenge in the remediation of oil-contaminated soils is limited amounts of nutrients, specifically, nitrogen and phosphate, to support microbial biodegradation of hydrocarbons. This can require the addition of nitrogen fertilizer to stimulate the soil, adding additional costs for site remediation. Fortunately, research on *P. vaginatum Sw* has identified several species of nitrogen-fixing and hydrocarbon-utilizing bacteria of the genera *Alcaligenes*, *Brevundimonas*, and *Klebsiella* in its rhizosphere soil. Therefore, the presence of *P. vaginatum*
Sw can provide soil microbes capable of degrading PHCs, while also fixing nitrogen into the soil. Not only does this reduce environmental toxicity, but the provision of available nitrogen is important as this often limited nutrient supports plant growth and soil fertility. (Omotayo et al. 2017)

Another turfgrass, *Schoenoplectus corymbosus*, known in South Africa as Buffalo Grass, is common in wetlands in the WC, including along the Diep River in the Cape Town area (Mudumbi et al. 2014). *S. corymbosus* was determined to have the potential for use in water quality rehabilitation efforts in the Upper Olifants Catchment, South Africa. Along with *Typha capensis* and *Phragmites australis*, the plant is promising for the accumulation and phytostabilization of aluminum, iron, and manganese. Both *S. corymbosus* and *T. capensis* may particularly be among the best candidates for manganese phytoextraction from water (Schachtschneider et al. 2017). With a 12-day contact time, *S. corymbosus* may also remove up
to 89.3% and 89.7% of TSS and nitrate, respectively (Mahdiana et al. 2018). This would meet the City requirement to remove at least 80% of TSS from stormwater.

Further, a study in the Diep River concluded that *S. corymbosus* has some capacity to accumulate Perfluorooctanoic acid (PFOA). PFOA is one of the most common Perfluorinated compounds that are found in the environment as a result of human uses in fire-extinguishing foams, non-stick cookware, and cleaning products, among many others. (Mudumbi et al. 2014)

And in their review of literature on the potential for using indigenous WC species in phytoremediation, Jacklin et al. Jul 2021, cite the ability of *S. corymbosus* to remove magnesium as well.

*Phragmites australis*, Common Reed

The Common Reed, *Phragmites australis*, is also common in South African wetlands (Cabi). Among the five phytoremediators growing in the RPP, *P. australis* may be able to remove the largest range of the aforementioned CECs, namely aluminum, nitrate, TSS, lead, copper, and zinc (Schachtschneider et al. 2017; Sahar Moghaddam et al. 2018; Cicero-Fernández et al. 2017; Jacklin et al. 2021). The plant is also capable of removing many other pollutants as listed in Appendix C. *P. australis* is a phytostabilizer of copper, cadmium, lead, cobalt, and iron, and a phytoextractor of selenium, zinc, beryllium, and manganese (Cicero-Fernández et al. 2017). In
addition to removing heavy-metal contamination, *P. australis* has high removal efficiency of nutrients in industrial effluents, particularly nitrates and TSS (Sahar Moghaddam et al. 2018).

![Typha Capensis](image1.jpg) ![Typha Capensis](image2.jpg)

*Typha Capensis*, Bulrush

The Bulrush (*Typha Capensis*) is a macrophyte spread throughout Southern Africa that inhabits slow-moving, shallow water, as well as, on the edge of freshwater, including ponds, lakes, rivers, etc. There are numerous phytoremediation studies that confirm *T. Capensis* as being a very promising phytoremediator for sites contaminated with heavy metals. The plant is reported to have a large capacity to accumulate aluminum, selenium, iron, manganese, mercury, arsenic, cadmium, lead, zinc, copper, cobalt, and nickel (Schachtschneider et al. 2017, Wiafe et al. 2018, Zaranyika and Nyati 2017, Wiafe et al. 2020, Jacklin et al. 2021). According to Zaranyika and Nyati 2017, *T. Capensis* roots are hyper-accumulators of zinc, copper, cobalt, nickel, and iron. The plant shoots are hyper-accumulators for zinc, copper, cadmium, and iron. Other studies also found a significant accumulation of arsenic, cadmium, and mercury in *T. Capensis* roots, as well as both the absorption and stabilization of lead in
plant shoots and roots, respectively (Wiafe et al. 2018; Wiafe et al. 2020). As reflected in the above literature, T. Capensis has consistently been an effective phytoremediator of many heavy metals, with various methods of accumulation.

**Root Depth**

There is much literature in support of the use of Cyperus rotundus, Schoenoplectus corymbosus, Phragmites australis, Typha capensis, and Paspalum vaginatum Sw. as native phytoremediators in BGI initiatives in Cape Town and possibly the WC overall. However, there may be various biotic and abiotic factors that could limit their effectiveness in remediating polluted sites, including the concentration of contaminants in soil, climate, soil type and quality (e.g. nutrient availability, pH, etc.), as well as the time of exposure to contaminants (Cicero-Fernández et al. 2017; Sahar Moghaddam et al. 2018; Mudumbi et al. 2014; Wiafe et al. 2020; Mahdiana et al. 2018).

Plant root depth should also be considered as a factor for remediation potential. At the RPP site, the groundwater is as deep as 0.45 m below ground. Therefore, plant roots long enough to have contact with the full soil column might be an important consideration, especially given the uncertainty on how water will infiltrate the pond after building a sandbag wall in front of the inlets and before the wetland. The effects of the sandbag installation, if any, are unknown. One possible effect of this structure may be that, while rainfall will still fall over the entire pond area, stormwater coming from the inlets will mostly infiltrate before the wetland and thus will not fill the wetland unless there is spillover above the sandbag wall. In such case, plant roots that can reach the full soil column and groundwater below may be more effective at filtering stormwater and possibly groundwater below the pond.

Unfortunately, not much literature was found on the root depths of the native vegetation at the Pond. However, strandveld and fynbos vegetation are generally known to have shallower root systems. Only two studies correlated the native Pond vegetation’s root structure to higher absorption of contaminants (Mudumbi et al. 2014; Basumatary et al. 2013). For example, common wetland species in the WC, including both those that are indigenous and introduced, seem to be more effective in accumulating PFOA with fibrous root structures, rather than taproots. Even P. australis has a taprooting structure, but was among the highest accumulators of PFOA in the Diep River, likely due to the small shoots that line its taproot and extend laterally.
Such laterally extensive root structures, especially those that are fibrous, are thus advantageous as they provide larger rhizospheric volume and surface area for the absorption of contaminants (Mudumbi et al. 2014).

More research is needed to further understand the plant characteristics of native species that enhance their ability to remediate soil and water in practice. Actual implementation and monitoring of WC species in BGI will be very useful in understanding the effectiveness, efficiency, and operation of biofilters in the Cape Town context.

Water Management—Water Quantity

Likely related to this lack of literature on the effect of WC plant root structure on phytoremediation, there was no literature exploring how WC vegetation may affect soil porosity and thus ground infiltration of water. Hua et al. determined that plant roots shorten the retention time of water, showing a slight increase in soil porosity. It was expected there might be similar trends for WC native species.

One noticeable tradeoff, however, for an increased quantity of water infiltrated may be the limited ability of phytoremediators to improve water quality. Longer contact time with contaminants increases removal (Mahdiana et al. 2018), so shorter retention times will likely result in less opportunity for filtration. For SuDS design in Cape Town, one might have to balance between priorities for improving the quantity or quality of water infiltrating into the CFA.

Ecological Sustainability and Resilience

In designing multi-BGI, ecological health and systems should also be prioritized to support urban resilience as well as to ensure the long-term sustainability of the infrastructure and its functions. The native vegetation at the Pond offer several ecological services that may benefit the site’s ecological sustainability and resilience, regarding their biotoxicity, use as contamination indicators, and survival in extreme climates or heavily polluted environments. These attributes are essential to feeders of the vegetation, and thus play a critical role in the food chain, and are also important for maintaining the long-term ecological health of the RPP.

*C. rotundus* and *P. australis* are both phytoremediators of water and soils contaminated with heavy metals. *C. rotundus* is a hyper-phytostabilizer of copper. The plant binds the pollutant
to its roots and the sediments around them, stabilizing the copper in this rhizospheric area. The
copper is therefore trapped in the roots and soil below *C. rotundus* plants and is not taken up by
the roots and into above-ground plant tissue. By stabilizing heavy metals in the soil, *C. rotundus*
is beneficial as a phytoremediator that is non-toxic and, thus, can be foraged safely (Jahan-Nejati
et al. 2021).

Similarly, *P. australis* is also a phytostabilizer of heavy metals, specifically, nickel,
arсенic, lead, selenium, barium, chromium, copper, iron, manganese, and zinc (Cicero-Fernández
et al. 2017; Bonanno and Giudice 2009; Gacia et al. 2020). The plant also, however, removes
heavy metals through absorption from water or sediments and translocates these metals to
aboveground plant tissue. This uptake of heavy metals has been found to eventually accumulate
in *P. australis* organs. This high accumulation of toxic metals poses a health risk to feeders of
this vegetation, and therefore, causes concerns for potential bioaccumulation in contaminated
sites (Rzymski et al. 2013).

While this high accumulation of heavy metals in the above-ground tissue of *P. australis*
may result in adverse effects down the food chain, the plant’s ability to remove pollutants via
both phytostabilization and root uptake makes it useful as a dual indicator of site air and soil
contamination (Bonanno and Giudice 2009; Gacia et al. 2020).

Another advantage of plant species used in land rehabilitation and recovery is that they
are usually able to survive in harsh climates and toxic environments. The symbiosis between
plants and microbes allows both to adapt to various soil conditions. Further, to ensure
colonization, root-colonizing bacteria are highly competitive, such that they possess favorable
traits to survive in harsh environments, including resistance to chemical toxicity and pathogen
disease. Therefore, the mutualisms between plants and bacteria, especially those able to adapt
together in extreme environments, are critical to ecosystem sustainability and resilience.

Aside from providing non-toxic plant tissues for primary consumers, *C. rotundus* is also
associated with several bacteria that thrive in extreme conditions and support the plant’s stability
and growth. A study of rhizosphere soil at an active lead and zinc mining site in China found that
bacteria colonies of *Halomonas, Pelagibacterium, and Chelativorans* exhibit long-term salinity-
and metal-tolerance. All three bacteria communities grow well in high-salinity environments.
Additionally, *Halomonas* promotes plant growth as it is able to continue the production of indole
acetic acid and soluble phosphate even in the presence of high salinity and high concentrations of heavy metals. (Gao et al. 2021).

Various factors shape plant-associated soil microbial communities, including soil conditions and plant genotypes (Gao et al. 2021). Therefore, there is a possibility that the dominant bacteria and their traits may be different in Cape Town contaminated sites with variations even within the Cape Town Area. Nevertheless, resilient microbial communities like those typically associated with phytoremediating species like *C. rotundus* will support the long-term health of the Pond ecosystem by ensuring vegetation cover and soil microbe activity even if site pollution might worsen over time.

Site resilience and sustainability are also supported by plant species that will be able to adapt to South Africa’s expected drying conditions due to climate change (Madonsela et al. 2018). Cathey et al. 2013 compared the response to soil drying of three species of turfgrasses: *Paspalum notatum Flugge* (Bahiagrass), *Stenotaphrum secundatum* (St. Augustinegrass), and *Zoysia japonica Steud.* (Zoysiagrass). *Stenotaphrum secundatum*, a native species identified at the RPP, along with *Zoysia japonica Steud.*., were more water-conservative than *P. notatum Flugge*. *S. secundatum* and *Zoysia japonica Steud.* had lower transpiration rates even when well-watered. Additionally, both species showed a significant decline in their transpiration rates at higher fractions of transpirable water in the soil—0.16 and 0.19, respectively—whereas *P. notatum Flugge* did not decrease its daily transpiration rate until the fraction of transpirable water reached 0.13. The difference between the transpiration breakpoint for *S. secundatum* and *Zoysia japonica Steud.* were not statistically different at the 95% confidence level, showing that both are similarly more drought-resistant and water-conservative than *P. notatum Flugge*. These results from Cathey et al. 2013 show that ground cover of *S. secundatum* could contribute to the Pond site resilience as Cape Town’s climate becomes drier and more water scarce. Rainfall in South Africa is already highly variable in time and space and is likely to become more infrequent (Madonsela et al. 2018). The possible tolerance of *S. secundatum* to severe drought stress might also reduce effects on stormwater infiltration at the Pond and help to maintain soil moisture during drier climates, thus supporting soil health and ecology.

In addition to understanding the ecological services provided by the native plant species currently present at the RPP, this study also sought to find other native plant species that could be added to the Pond site, specifically Cape Flats Dune Strandveld plant species, which are endemic
to the Cape Flats region where Mitchells Plain is situated. During the last 30 years, over half of strandveld vegetation has been lost due to urbanization. Only 14% is conserved today (CPT 2010). Therefore, including these native species in the Pond design might provide opportunities for urban conservation of these plant communities, and may also help to improve the site biodiversity of local vegetation and therefore possibly support ecological resilience (Jacklin et al. Aug 2021).

There are a few nature reserves that are actively conserving Cape Flats Dunes Strandveld vegetation. Between the Wolfgat Nature Reserve and the Massacar Dunes Nature Reserve, there was more literature on the plant species conserved at Wolfgat. The reserve is less than 9 km from the RPP, over 248 ha, and hosts more than 150 species of strandveld vegetation (CPT 2010). According to Britton et al. 1995, the most common species at the reserve, as well as, over the Cape Flats region more generally are *Chrysanthemoides monilifera*, *Rhus lucida*, *Euclea racemosa*, *Salvia africana-lutea*, *Pterocelastrus tricuspidatus*, *Eriocephalus racemosus*, *Metalasia muricata*, *Nylandtia spinosa*, and *Restio Ischyrolepis eleocharis*. There are not many studies on the ecological services these plant species may provide for humans and the ecosystems they support. However, as native plant species common throughout the region, their value to ecosystem functioning and resilience is likely immeasurable as they are somehow intricately linked in native ecosystems and are well-adapted to the coastal environment at the Pond site in terms of climate and soil types. Developing such biodiversity in strandveld vegetation could thus help to build a more sustainable and self-sufficient ecosystem at the Pond.

According to Milandri et al 2012, biodiversity in phytoremediators may also be an effective way to optimize stormwater filtration, as each plant has varying capacities for removing different pollutants. The combination of various species would optimize pollutant removal and efficiency. In addition to *J. effusus* mentioned earlier, Jacklin et al. Aug 2021 lists 56 phytoremediators that are endemic to the WC, which can be used for reference of native species that could be added to the Pond to enhance stormwater filtration.
**Placement of plants**

The below information in Table 1 summarizes the habitats the 15 native vegetation identified at RPP prefer. This will inform the pond design to hopefully optimize each species’ multi-BGI attributes.

Table 1: Native species identified at RPP, their multi-BGI components, and preferred habitat

<table>
<thead>
<tr>
<th>Ecology</th>
<th>SUDs</th>
<th>Social</th>
<th>Environment</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Searsia laevigata</strong></td>
<td></td>
<td></td>
<td>sandy (fynbos)</td>
<td><a href="https://www.steenboknaturereserve.org.za/flora/trees/searsia-laevigata/">https://www.steenboknaturereserve.org.za/flora/trees/searsia-laevigata/</a></td>
</tr>
<tr>
<td><strong>Cyperus rotundus</strong></td>
<td></td>
<td></td>
<td>wet</td>
<td><a href="https://plants.ces.ncsu.edu/plants/cyperus-rotundus/">https://plants.ces.ncsu.edu/plants/cyperus-rotundus/</a></td>
</tr>
<tr>
<td><strong>Schoenoplectus corymbosus</strong></td>
<td></td>
<td></td>
<td>water plant (shallow, 6in)</td>
<td><a href="https://plants.ces.ncsu.edu/plants/schoenoplectus-lacustris/">https://plants.ces.ncsu.edu/plants/schoenoplectus-lacustris/</a></td>
</tr>
<tr>
<td><strong>Phragmites australis</strong></td>
<td></td>
<td></td>
<td>wet</td>
<td><a href="https://www.cabi.org/isc/datasheet/40514#tosummaryOfInvasiveness">https://www.cabi.org/isc/datasheet/40514#tosummaryOfInvasiveness</a></td>
</tr>
<tr>
<td>Plant Name</td>
<td>Habitat Details</td>
<td>Water Requirement</td>
<td>Source Link</td>
<td></td>
</tr>
<tr>
<td>------------------------------------</td>
<td>----------------------------------</td>
<td>-------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Stenotaphrum secundatum</td>
<td></td>
<td>wet</td>
<td><a href="https://plants.ces.ncsu.edu/plants/stenotaphrum-secundatum/">https://plants.ces.ncsu.edu/plants/stenotaphrum-secundatum/</a></td>
<td></td>
</tr>
<tr>
<td>Typha capensis</td>
<td></td>
<td>wetland (in water)</td>
<td><a href="https://www.plantbook.co.za/typha-capensis/">https://www.plantbook.co.za/typha-capensis/</a></td>
<td></td>
</tr>
<tr>
<td>Paspalum vaginatum Sw.</td>
<td></td>
<td>wet</td>
<td><a href="https://www.cabi.org/isc/data-sheet/110291">https://www.cabi.org/isc/data-sheet/110291</a></td>
<td></td>
</tr>
<tr>
<td>Geranium incanum</td>
<td>semi-shade/medium water/ edge of wetland</td>
<td></td>
<td><a href="https://www.plantbook.co.za/?s=Pelargonium+capitatum">https://www.plantbook.co.za/?s=Pelargonium+capitatum</a></td>
<td></td>
</tr>
<tr>
<td>Leonotis leonurus</td>
<td></td>
<td>medium water (fynbos)</td>
<td><a href="https://www.plantbook.co.za/?s=Pelargonium+capitatum">https://www.plantbook.co.za/?s=Pelargonium+capitatum</a></td>
<td></td>
</tr>
<tr>
<td>Pelargonium capitatum</td>
<td></td>
<td>sandy (fynbos)</td>
<td><a href="http://pza.sanbi.org/pelargonium-capitatum">http://pza.sanbi.org/pelargonium-capitatum</a></td>
<td></td>
</tr>
<tr>
<td>Plant Name</td>
<td>Habitat</td>
<td>Variety</td>
<td>Additional Information</td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Cyperus polystachyos</strong></td>
<td>wetland margins, sandy</td>
<td></td>
<td><a href="https://gobotany.nativeplanttrust.org/species/cyperus/polystachyos/">https://gobotany.nativeplanttrust.org/species/cyperus/polystachyos/</a></td>
<td></td>
</tr>
<tr>
<td><strong>Pennisetum clandestinum</strong></td>
<td></td>
<td>variety</td>
<td><a href="https://www.cabi.org/isc/datasheet/39765#tosummaryOfInvasiveness">https://www.cabi.org/isc/datasheet/39765#tosummaryOfInvasiveness</a></td>
<td></td>
</tr>
<tr>
<td><strong>Monopsis lutea</strong></td>
<td>sandy, wetlands (host of insect pollinators, including butterflies and megachilid bees, and the fruit capsules are the bonnes bouches of seed-eating birds)</td>
<td></td>
<td><a href="https://www.fynboslife.com/plantprofile/monopsis-lutea/">https://www.fynboslife.com/plantprofile/monopsis-lutea/</a></td>
<td></td>
</tr>
</tbody>
</table>
Social Amenity

All of the above possible benefits to water management and ecology at the RPP are attributed to only five plant species: *Cyperus rotundus*, *Schoenoplectus corymbosus*, *Phragmites australis*, *Typha capensis*, and *Paspalum vaginatum* Sw.. Another three native plant species identified at the Pond have social attributes that may benefit the surrounding Rondevlei community and perhaps Mitchells Plain more generally.

In South Africa, most medicines consumed are plant-derived. According to health experts, over 1000 plant materials are used medicinally for internal and external applications (Babajide et al. 2010). *Geranium incanum* (Carpet Geranium), *Leonotis leonurus* (Wild Dagga), *Pelargonium capitatum* (Rose-scented Geranium) all have shown anti-microbial abilities (Babajide et al. 2010; Amabeoku 2009; El-Ansari et al. 2009; Rafiq et al. 2016). *G. incanum* has historically been used as a herbal remedy for various ailments, and is named “vrouebossie, amarabossie” in Afrikaans and “ngope-sethosha’tlako” in Sotho. It is traditionally used to treat colic, diarrhea, fever, bronchitis, bladder infections, venereal diseases, and menstruation-related ailment (Babajide et al. 2010). One study (Amabeoku 2009) sought to support such traditional uses of the plant with experiments on the response to *G. incanum* extracts in mice. *G. incanum* was found to exhibit anti-viral and anti-diarrhoeal properties. As little as 25 mg/kg of leaf extract could delay the onset of diarrhea and also significantly reduce the fecal output from the mice studied (Amabeoku 2009). Leaf extracts of *L. leonurus* were also tested on mice, with findings confirming anti-microbial as well as anti-inflammatory properties (El-Ansari et al. 2009). And compared to two other essential oils, extracts from *P. capitatum* showed the most effective anti-microbial properties against two common food-borne microbes, *Salmonella typhimurium* and *Escherichia coli*. These findings offer *P. capitatum* as a natural alternative to prevent contamination in food products. Its essential oils might also provide health benefits to consumers, unlike common synthetic anti-microbials that can be associated with negative health effects (Rafiq et al. 2016). Moreover, all three species were found to be generally safe to consume (Amabeoku 2009; El-Ansari et al. 2009; Rafiq et al. 2016). Although, hypoactivity was observed in mice that consumed over 4000 mg/kg of *G. incanum* extracts (Amabeoku 2009).

Aside from a multitude of medicinal benefits, re-designing the Pond to be more inclusive and dominated by native plants may also involve social benefits in terms of safety. The City of Cape Town lists that, of all South African cities, Cape Town experiences the highest incidence of
murder, attempted murder, sexual assault, common assault, and robbery (Potgieter et al. 2019). During a workshop between the Future Water PaWS team and residents of Rondevlei, Mitchells Plain, residents stressed their concern for safety. Therefore, PaWS was asked to keep the RPP an open space with few trees and large bushes for criminals to hide in.

A study from Stellenbosch University reviewed around 4300 court cases and used questionnaire-based surveys to examine the relationship between vegetation structure and criminal activity in Cape Town. In Cape Town, vegetation structure has been drastically altered by invasive species, particularly alien tree invasions. The study concluded that criminal activity is more likely to occur around communities of invasive non-native vegetation compared to those dominated by native species. Native vegetation in Cape Town, like fire-dependent fynbos, are mostly short in stature, especially due to fires occurring more frequently. In contrast, many invasive species, are tall and form dense columns that provide ideal places for criminals, including robbers and prostitutes, to hide. Even relatively tall and dense stands of fynbos are still not as tall and aggressive as invasive species, which are less sensitive and more resilient against some of the major human disturbances in Cape Town’s urban environment. The Australian Acaia species, for example, introduced to Cape Town in the mid-nineteenth century, has been problematic in its invasiveness and has also been linked to criminal activity in several other studies. (Potgieter et al. 2019)

Despite some fynbos vegetation like S. laevigata, the Pond is located in the Cape Flats Dune Strandveld rather than being among fynbos where the study is based. The vegetation stature, however, still tends to be much the same as fynbos shrubs. Therefore, aside from supporting ecological health, ensuring the dominance of native species in the Pond may thus also have positive implications for reducing safety risks.
**Design**

Figure 13: Pond Site 3D Model

Based on findings from literature about the native vegetation at the Pond and their attributes to multi-BGI, as well as, general requests gathered by Future Water from the Rondevlei community, a 3D rendering of the RPP re-designed as multi-BGI was created. There is still much to be known about the Pond, including soil type and distribution, CECs in stormwater and groundwater, and there are still ongoing, more formalized interviews with residents to understand their hope and desires for the Pond and the ways it can serve their community. From what is already known and found in this study, water management, safety, community education, and community leisure were prioritized for the spatial design of the 3D rendering. Because of many unknowns, this rendering is only a proposal to show how the Lähde et al. 2019 framework may be used to re-design the pond as multi-BGI. In addition, the model only includes the native vegetation currently at the Pond. The additional vegetation recommended above can be selected and incorporated in future renderings according to further studies around introducing them into this site.
The placement of vegetation was based on Table 1. The design places two separate gardens of native vegetation in the lower elevations of the pond, shown in Figure 14. A table in Appendix D lists all of the species in each garden. The Biofilter Wetland is in the lowest elevation and includes the five phytoremediors as well as all of the other native wetland plants, such as Lobelia aniceps, Cyperus polystachyos, and Monopsis lutea. Rain and stormwater will collect here, at the lowest elevation, and so will likely provide the wet conditions these species require, while also optimizing exposure for polluted water entering the pond to be filtered before infiltration into the ground. Around the wetland, at slightly higher elevations, will be the Medicinal-Eco-Garden. This garden will host species that prefer drier conditions, such as Plecostachys serpyllifolia, as well as wetland edge, like Cyperus polystachyos. Many of the species in this garden have flowers that attract birds, butterflies, and other pollinators and insects.

Signs can provide opportunities for the community to learn about the native vegetation in each garden, the function of the pond, and the ecological services the plants provide to support the community and the pond ecologically and in terms of water management. There is a primary school located right next to the pond, giving the classes there access to outdoor learning opportunities right at their doorstep.
The biggest safety hazards Rondevlei residents identified were large and thick vegetation that might be ideal for criminals to hide in and the lack of places for children to safely play near the wetland, as there are many holes and trenches covered by dense vegetation that are easy to fall in. As shown in Figures 13 & 14, the Pond design is opened as much as possible for a full view of the pond from any point and might also address concerns in a few other ways.

A boardwalk could be placed over the wetland and the draining channel that leads to the outlet. This might prevent people of all ages from falling into trenches and will make it easier for people to explore the wetland at a closer look. Stones could also be laid around the wetland to mark the areas where the Pond gets deeper and may have trenches. People, children especially, will hopefully be more cautious to not enter this area unless necessary (e.g. to find lost items).

Furthermore, on the side of the Pond opposite the wetland in Figure 15, are Wild Olive trees (Olea europaea subsp. africana). These indigenous trees have relatively skinny trunks but a dense crown that can provide shade, which was another feature requested by residents so that the space could be enjoyed even under Cape Town’s intense summer sun. These Wild Olive trees will also support the Pond ecology, as they attract birds like red-winged and pied starlings, while also entertaining residents who might enjoy bird-watching or peaceful walks with bird-song. (PlantZAfrica)
Moreover, this green space should be inviting for residents to enjoy as their own and as a space in their neighborhood for leisure and recreation. In the rendering (Figure 16), there are benches in the shade of the Wild Olive trees and on the higher elevations, looking out over the Pond. On the far side of the Pond near the Olive Trees are also large rocks, smooth and low enough to the ground, for either children to play on or to use as another place to sit. Furthermore, there should be ample space for children to play ball games or run around, with the rock boundary around the wetland hopefully keeping them away from more dangerous parts of the pond area. PaWS is also in the process of planning a mural to tell the story of Future Water and the work they are doing at the RPP as a part of the PaWs project.

**Considerations for Maintenance**

Multi-functional BGI emphasizes the importance of sustainability, regarding how infrastructure can be a part of sustainable water management, and provide long-term benefits for society, while also prioritizing ecological health and resilience. A part of this long-term outlook on the life of BGI infrastructure also involves considerations for long-term maintenance. Aboveground plant materials are usually harvested so that absorbed contaminants are not returned to the soil after aboveground tissues die and decompose. Cicero-Fernández et al. 2017
looked at the long-term use of *P. australis* to reduce heavy metal site pollution to below standards given by current Spanish regulations. The results of the study suggested that aboveground tissues should be harvested for nickel, chromium, and molybdenum removal in the fourth year. On the other hand, lead, zinc, and cadmium are absorbed mostly in belowground tissues, which should be harvested for their removal after 5 years. Cadmium is also absorbed into the plant roots of *P. australis*, but requires up to 10 years before harvesting (Cicero-Fernández et al. 2017). Although this study for “full” site remediation is not based on South African regulations, this study may still be applicable in providing estimates for the time one can expect to prepare for harvesting and see significant improvement in metal pollution.

However, it is still important to realize that the performance of phytoremediation is highly variable and dependent on various environmental factors, such as soil and climate (Sahar Moghaddam et al. 2018). These estimates for site clean-up can also be highly variable within a site as well, especially since plants may become damaged by pests and animals, extreme weather events, or could uptake contaminants at a faster rate than expected. In these cases, the plants would have to be replaced.

Different pollutants will also require more or less time for cleanup (Cicero-Fernández et al. 2017). Hence why it is important to know the CECs particular to a BGI site so that the plant species and appropriate harvesting time can be determined to optimize contaminant removal. The above are all reasons for more research to understand the long-term use and maintenance of native phytoremediators like *P. australis* in BGI projects in Cape Town.

Some other questions for further study might be to what extent the soil around phytostabilizers also needs to be removed and how such routine harvesting might disturb the ecosystem, especially as the soil nutrients and microbes might be affected by plant uprooting. In addition, plant biofilters are typically implemented as a low-cost alternative in sustainable water management. However, long-term maintenance might incur unforeseen costs depending on how often harvesting is needed. There are costs associated with labor, new plants or seeds, and tools for harvesting. Estimates for these costs in Cape Town might make investing in and planning for multi-BGI projects more feasible.
Conclusion

The Lähde et al. 2019 framework—water management, ecological sustainability and services, and social amenity—was a useful outline for re-designing the RPP as multi-BGI. Furthermore, the native vegetation at the pond were surprisingly quite versatile in their ecological services. Based on literature, more than half of the native plants identified at the Pond (eight out of 15) provided at least one ecological service that was attributed to one of the multi-BGI components. Research suggests that five of the native species are effective phytoremediators of 21 different contaminants ranging from anthropogenic chemicals to heavy metals. Most importantly, all five species combined are able to remove Cape Town CECs, assuming they are those found in Robertson 2017 and Ward 2014.

Further research can be done at the RPP to understand more site characteristics, including stormwater and groundwater CECs, soil quality and type distribution, and the spread of water infiltration over the Pond. The Pond design generated in this study could also be studied to practice implementation and to understand how site characteristics may affect the performance of the phytoremediating species. An annual sampling regime that accounts for seasonal variation would also be useful for site monitoring and maintenance (Robertson 2017).

Moreover, this framework for multi-BGI is relatively practical and can be applied across the CFA for the treatment of stormwater and the provision of green spaces. This study of native vegetation in local BGI, however, also highlights the importance of understanding site characteristics and context. There is a need for more research on the use of native WC plant species in BGI and ecosystem rehabilitation. For example, aside from studies on root structure in phytoremediation, there was limited information on the relationship between native plant root structure and soil porosity, or any other plant characteristics that might influence the quantity of stormwater infiltration.

In addition to studies on native vegetation, closer engagements with communities with the potential to implement multi-function BGI in Cape Town will produce surveys and guidelines outlining the economic and ecological services local residents would like to receive and benefit from BGI in their neighborhoods.

Also, soil and water contamination due to mining activities, especially of heavy metals, is a very big threat in South Africa. These methods and native phytoremediators might be used for site remediation in areas of South Africa where acid mine drainage is one of the largest
long-term threats to aquatic ecosystems and groundwater quality, such as in the Olifants River Catchment. (Gao et al. 2021; Madlala 2021).

**References**


OUR SHARED WATER FUTURE.

Some perceptions and preferences of residents' use of community neighbourhood parks in Mitchells Plain, Cape Town Lodene Willemse. Available: .


WOLFGAT NATURE RESERVE A desolate wasteland destined for housing or < i dynamic community conservation project? Available: .


Mauck, B. & Winter, K. (2021) Assessing the potential for managed aquifer recharge (MAR) of


Phragmites Australis (Common Reed), https://www.cabi.org/isc/datasheet/40514.


# Appendix

Appendix A: Species Collected

## Native

<table>
<thead>
<tr>
<th><em>Dune Currantrush</em></th>
<th>Searsia laevigata</th>
<th>Endemic, native</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bulrush</em></td>
<td><em>Typha capensis</em></td>
<td>Indigenous</td>
</tr>
<tr>
<td>angled lobelia</td>
<td><em>Lobelia anceps</em></td>
<td>Indigenous</td>
</tr>
<tr>
<td><em>Plume sedge</em></td>
<td><em>Schoenoplectus corymbosus</em></td>
<td>Indigenous</td>
</tr>
<tr>
<td>Native Plant</td>
<td>Scientific Name</td>
<td>Native Status</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------</td>
<td>---------------</td>
</tr>
<tr>
<td><em>bunchy flat-sedge</em></td>
<td><em>Cyperus polystachyos</em></td>
<td>native</td>
</tr>
<tr>
<td><em>Purple Nutsedge</em></td>
<td><em>Cyperus rotundus</em></td>
<td>native</td>
</tr>
<tr>
<td>Common Lianspaw</td>
<td>Leonotis leonurus</td>
<td>native</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------</td>
<td>--------</td>
</tr>
<tr>
<td>*Rose-scented Geranium</td>
<td>Pelargonium capitatum</td>
<td>native</td>
</tr>
<tr>
<td>*Brak Paspalum</td>
<td>Paspalum vaginatum Sw.</td>
<td>redlist (native)</td>
</tr>
<tr>
<td>Species</td>
<td>Scientific Name</td>
<td>Native Status</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Petite-licorice</td>
<td><em>Plecostachys serpyllifolia</em></td>
<td>indigenous</td>
</tr>
<tr>
<td>Monopsis lutea (Genus: oneeye)</td>
<td><em>Monopsis lutea</em></td>
<td>Native</td>
</tr>
<tr>
<td>*Carpet Crane's-bill</td>
<td>*Geranium incanum</td>
<td>Native</td>
</tr>
<tr>
<td>----------------------</td>
<td>------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Sait Augustine Grass</td>
<td>*Stenotaphrum secundatum</td>
<td>Native</td>
</tr>
<tr>
<td>*Common Reed</td>
<td>*Phragmites australis</td>
<td></td>
</tr>
</tbody>
</table>
### Introduced

<table>
<thead>
<tr>
<th>plant</th>
<th>scientific name</th>
<th>introduction status</th>
</tr>
</thead>
<tbody>
<tr>
<td>curled dock</td>
<td>Rumex crispus</td>
<td>introduced</td>
</tr>
<tr>
<td>fox sedge</td>
<td>Carex vulpinodea</td>
<td>introduced</td>
</tr>
<tr>
<td>Hare's Tail Grass</td>
<td><em>Lagurus ovatus</em></td>
<td>introduced</td>
</tr>
<tr>
<td>Perennial Wall-rocket</td>
<td><em>Diploptaxis tenuifolia</em></td>
<td>introduced</td>
</tr>
<tr>
<td>strawberry clover</td>
<td><em>Trifolium fragilis</em></td>
<td>introduced</td>
</tr>
<tr>
<td>rabbit foot grass</td>
<td><em>Trifolium fragilis</em></td>
<td>introduced</td>
</tr>
<tr>
<td>American Coinwort/ Pennywort (genus)</td>
<td>Centella sp. (genus)</td>
<td>not observed on seek in area</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>----------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>cogon grass</td>
<td>Imperata cylindrica</td>
<td>introduced</td>
</tr>
<tr>
<td>timothy grass (some type of Plaintain)</td>
<td>Phleum pratense</td>
<td>introduced</td>
</tr>
<tr>
<td>Orange Milkwort</td>
<td>Polygala lutea</td>
<td>?</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------</td>
<td>---</td>
</tr>
</tbody>
</table>

![Image of Orange Milkwort](image-url)
<table>
<thead>
<tr>
<th>Genus:</th>
<th>clovers</th>
</tr>
</thead>
<tbody>
<tr>
<td>St Johns Worts Genus/Senecioninae Family</td>
<td>senicio</td>
</tr>
<tr>
<td>Zeltnera (genus)/Meadow Pink</td>
<td>Sabatia campestris</td>
</tr>
</tbody>
</table>
Family: Sedge
### Appendix B: RPP nutrient test results (25/06/21, 20/06/21, 06/04/22)

<table>
<thead>
<tr>
<th>SampleID</th>
<th>Sample Point</th>
<th>Sample Date</th>
<th>Temp</th>
<th>pH</th>
<th>EC</th>
<th>EC</th>
<th>GP</th>
<th>DO</th>
<th>NH₄-N</th>
<th>NO₂-N</th>
<th>NO₃-N</th>
<th>Total N</th>
<th>PO₄-P</th>
<th>TOC</th>
<th>C</th>
<th>Cu</th>
<th>Cr</th>
<th>Al</th>
<th>Fe</th>
<th>As</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW-250621</td>
<td>SW</td>
<td>6/25/21</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>0.35</td>
<td>0.02</td>
<td>1.16</td>
<td>0.22</td>
<td>31.47</td>
<td>2419</td>
<td>44.7</td>
<td>2.1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SW-300621</td>
<td>SW</td>
<td>6/30/21</td>
<td>8.67</td>
<td>3.5</td>
<td>305</td>
<td>30.5</td>
<td>200</td>
<td>ND</td>
<td>0.27</td>
<td>0.04</td>
<td>1.29</td>
<td>0.34</td>
<td>93.32</td>
<td>&gt;2419</td>
<td>30.5</td>
<td>2.7</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SW-060422</td>
<td>SW</td>
<td>5/6/22</td>
<td>17.3</td>
<td>9.64</td>
<td>98</td>
<td>9.8</td>
<td>96</td>
<td>8.3</td>
<td>0.399</td>
<td>0.061</td>
<td>0.807</td>
<td>1.79</td>
<td>0.218</td>
<td>6.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

| µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Cu   | Fe   | Pb   | Mn   | Ni   | P    | Zn   | Al   | As   | Cr   | Cu   | Fe   | Pb   | Mn   | Ni   | P   | Zn   | Al   | As   | Cr   | Cu   | Fe   | Pb   | Mn   | Ni   | P    | Zn   |
| 5    | 16.7 | <0.4 | <1.5 | <1.5 | 0.5  | 239  | 77.2 | 552.4| 3.2  | 4.2  | 51  | 675.4 | 3.8  | 12  | 1.3 | 261 | 128.2 |

**Genus:** Willowherbs
Appendix C: Table of indigenous phytoremediator species at RPP and pollutants removed

<table>
<thead>
<tr>
<th>Species</th>
<th>Pollutant</th>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Cyperus rotundus</em></td>
<td>Petroleum hydrocarbons (PHC)</td>
<td>Basumatary et al. 2013</td>
</tr>
<tr>
<td><em>Paspalum vaginatum Sw.</em></td>
<td>PHC</td>
<td>Omotayo et al. 2017</td>
</tr>
</tbody>
</table>
Appendix D: Species in 3D pond design garden

<table>
<thead>
<tr>
<th>Biofilter Wetland</th>
<th>Medicinal-Eco-Garden (attracts birds and butterflies)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyperus rotundus</td>
<td>Searsia laevigata</td>
</tr>
<tr>
<td>Schoenoplectus corymbosus</td>
<td>Typha capensis</td>
</tr>
<tr>
<td>Phragmites australis</td>
<td>Euryops virgineus</td>
</tr>
<tr>
<td>Stenotaphrum secundatum (shallow water)</td>
<td>Leonotis leonurus</td>
</tr>
<tr>
<td>Typha capensis</td>
<td>Pennisetum clandestinum</td>
</tr>
<tr>
<td>Paspalum vaginatum Sw.</td>
<td>Geranium incanum</td>
</tr>
<tr>
<td>Pennisetum clandestinum</td>
<td>Cyperus polystachyos (wetland edge)</td>
</tr>
<tr>
<td>Lobelia anceps</td>
<td>Plecostachys serpyllifolia</td>
</tr>
<tr>
<td>Cyperus polystachyos (wetland edge)</td>
<td>Monopsis lutea</td>
</tr>
<tr>
<td>Monopsis lutea</td>
<td>Pelargonium capitatum</td>
</tr>
</tbody>
</table>