EFTEON LANDSCAPE PROPOSAL - September 2020

# The Greater Cape Town Long-Term Social-Ecological Research landscape (GCT-LTSER)


*Steenbras dam in the foreground and False Bay, Cape Flats and Table Mountain behind. (photo credit: Jean Tresfon, used with permission)*

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# Executive summary

The Greater Cape Metro provides an overabundance of opportunities for cutting edge and impactful long term environmental, social-ecological, urban and anthropological research. So much so that it could absorb the entire EFTEON budget and still have opportunity for further favourable return on investment. This potential, combined with the understandable limitation on resources, and uncertainty with regard to the available instrumentation and potential constraints on sampling strategies imposed by the design of the national EFTEON network, provides a significant challenge to developing a concise and fully developed proposal. Consequently, we have focused this proposal on highlighting the potential for this landscape to do cutting edge science that helps address some of the most relevant societal and environmental questions for the region and the South African developmental context. While the proposal highlights key research needs and opportunities, the specifics of sampling will need to be co-designed with local partners, stakeholders, the EFTEON leadership and EFTEON technical thematic committees, allowing this landscape to explore an overarching social-ecological systems approach from the start.

The key point of departure for this proposal is aligning the core focus of the landscape with the priority environmental and development challenges highlighted for the region in the national, provincial, regional and local policies and frameworks. Perhaps the most relevant overarching framework is the Greater Cape Metro Regional Spatial Implementation Framework (Department of Environmental Affairs and Development Planning 2019). This is a regional planning instrument aimed at integrating existing policies at all levels of government with the goal of incorporating economic, human settlement and environmental considerations into the development plans and frameworks of the City of Cape Town and surrounding municipalities. The main themes include the provision and management of energy, water, wastewater, waste and economic opportunity through the development, restoration or maintenance of appropriate ecological, transport and utility (electricity, water, sanitation) infrastructure. Each of these themes are further guided by specific policy documents such as the Western Cape Province's Sustainable Water Management Plan ("Western Cape Sustainable Water Management Plan" 2018), Ecological Infrastructure Investment Framework (Department of Environmental Affairs and Development Planning in prep), Climate Change Response Strategy (Department of Environmental Affairs and Development Planning 2014), and Biodiversity Strategy and Action Plan (Department of Environmental Affairs and Development Planning 2016), local policies like the City of Cape Town Water Strategy (City of Cape Town 2019), and many others. We propose to assemble this EFTEON landscape in a manner that it can support research aligned with these policies, to help track, unpack and communicate their successes and failures. Adopting this approach allows us to involve key stakeholders and decision makers as both participants in the research and beneficiaries of the knowledge produced, ensuring that the research agendas are shaped to inform decision making needs.

To maximize the footprint and impact of the proposed EFTEON landscape, despite limited resources, we have chosen a set of core upland and lowland quaternary catchments that complement existing monitoring and research run by partners within the Greater Cape Town region. Specifically, our proposed catchments allow us to tie together three complete catchments from source to sea. While there are many questions that can be addressed within each individual quaternary catchment, and the set of core EFTEON catchments can operate independently, having a network that covers complete catchment to coast continua provides a template that allows us to research (and inform) the key challenges faced by the greater Greater Cape Town region and beyond. Our proposed upland catchments cover the heart of the Boland Mountains, the most important Strategic Water Source Area in the Western Cape. The focus here will likely be on hydrometeorology and biodiversity, for which long term observations are surprisingly sparse given the area's importance. The main aims will be to explore the interaction between vegetation, climate, surface and groundwater systems in the context of changing climatic conditions, invasive species, catchment restoration initiatives and groundwater abstraction. The social-ecological linkages in the upland catchments are largely the regional teleconnection through the provision of water to lowland residents and agriculture, but there are many other linkages such as carbon storage, habitation, fire, tourism, and human health and wellbeing.

Our lowland catchments allow us to link the uplands to the coast and offer the opportunity to explore a broad range of key social-ecological challenges in urban and peri-urban settings. While we may need to patch or improve the network of hydrometeorological observations in these catchments, we envision that the focus of EFTEON's biophysical sampling efforts in the lower catchments will largely be on nutrients and pollutants and the implications that the trade-offs in land cover and land use have for surface and ground water quality and biodiversity. The continuum from the mountains to the sea also allows us to monitor the soil catena from the shallow soils in the upper slopes to the deep sands towards the coastal areas and the diverse aquifer types (e.g. fractured rock Table Mountain Group Aquifer and primary sandy Cape Flats Aquifer). Our selected lowland catchments differ in dominant land use and land cover; mostly in terms of different proportions and forms of natural, agriculture and urban. This allows exploration of the many different interactions between people and the environment at scales from the household or farm level up to the quaternary catchments or bigger. These lived-in lowlands also provide the opportunity to explore biodiversity ecosystem services and conservation issues from the ecology of gardens and green spaces to the challenges of conserving hyperdiverse fragments of unique and irreplaceable biodiversity in an urban setting. These issues are infinitely complex when set against a backdrop of historical social injustice and persistent economic disparity.

Linking our catchments to the coast of False Bay has several advantages. It allows us to link this EFTEON landscape with the Two Oceans Sentinel Site of the Shallow Marine and Coastal Research Infrastructure (SMCRI), who will be sampling the estuaries and near-shore environment and exploring the social-ecological systems of False Bay. This has potential cost-sharing benefits for EFTEON and SMCRI operations, but also provides the opportunity to be able to sample most components of the regional cycles of water, nitrogen and other nutrients within this broader landscape. This ability to sample from catchment to coast will be significantly complemented by the two local nodes of the Biogeochemistry Research Infrastructure Platform (BIOGRIP), who are equipped to process freshwater, terrestrial and marine samples to generate meaningful environmental datasets. Lastly, the existence of a large number of weather stations, the City of Cape Town's dense air quality monitoring network and the Global Atmospheric Watch station run by the South African Weather Service at Cape Point, means that the proposed landscape already has significant atmospheric observations that EFTEON can build on.

The Greater Cape Town region is very well suited to support an EFTEON landscape in terms of logistics, operational suitability and academic setting. There are several willing host institutions in addition to the potential for cost sharing by teaming up with SMCRI and/or existing SAEON offices. The road network provides easy access to sites, including four elevational transects of interest. Finally, the presence of two research councils and four tertiary institutions, which host a number of relevant Centres of Excellence, SARChI chairs and other research hubs, means that the landscape will be well supported and heavily utilized by the academic community.

# General Details of the Landscape

## Landscape Name

Greater Cape Town Long-Term Social-Ecological Research site (GCT-LTSER)

## List of collaborators

Most individuals who participated in and contributed to the development of this proposal are listed here. The support of institutions and other bodies are indicated through the letters of support.

## Spatial extent

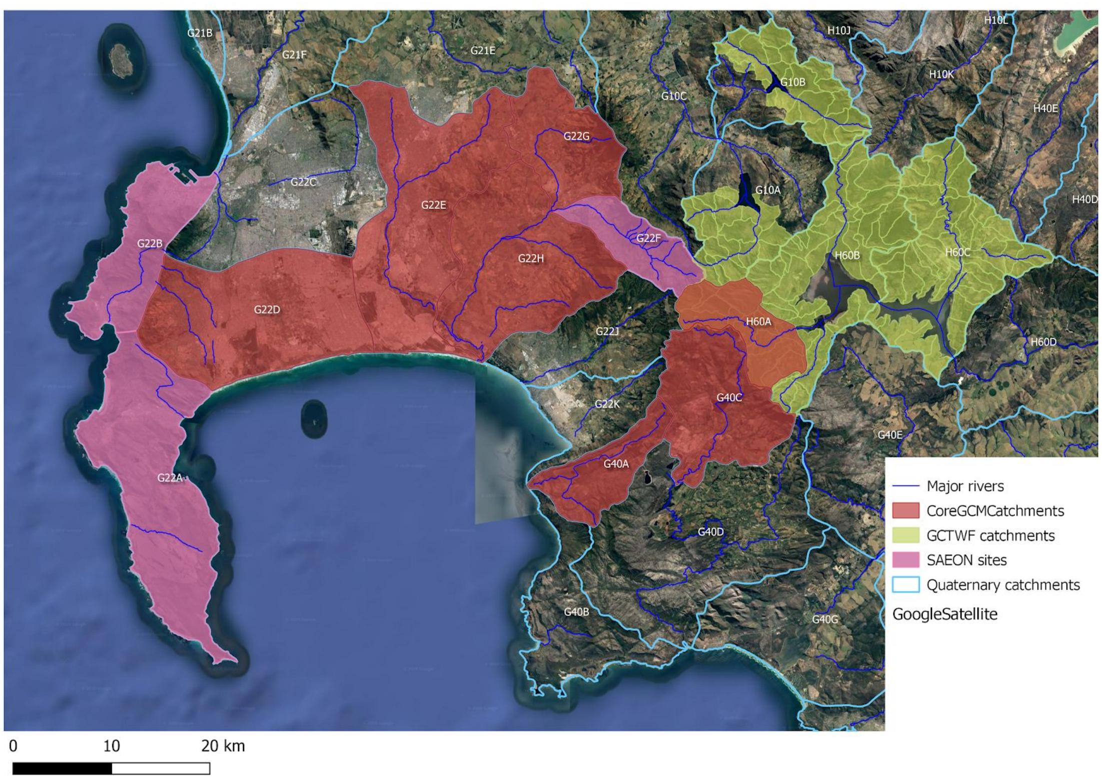
### Rationale

The Greater Cape Town LTSER is an extensive landscape that from conception intends to examine processes and their dynamics at several different scales. The Greater Cape Metro Region is proposed to be the broad, overarching domain of this EFTEON landscape. This recognises that the dynamics of the City has implications for ecological processes and function well beyond current urban and exurban areas (Grimm et al. 2000), with reciprocal relationships between the urban systems and their supporting hinterland and oceans. For example, the City is highly dependent on neighbouring catchments (particularly in the Boland Mountains) to service its bulk water needs. Similarly, the City's relationship with and management of water and waste determine outflows into the marine environment, with further impacts and feedbacks such as for fisheries, recreational use or harmful algal blooms. Without considering biophysical, ecological and social mechanisms as integrated drivers of systems dynamics, our understanding of ecosystem function will be incomplete. Equally, we recognise that there are a number of important questions and issues that require much finer scales of observation. The effects of scale, both spatially and temporally, are intricate and thus, in adopting an integrated approach, multiple scales of observation are required.

Our nested or hierarchical approach allows the scales of observation to relate directly to the scales of the questions and themes addressed. While we have left the overarching domain broad and relatively flexible, our research framework comprises primarily core sites where the co-located observation instrumentation will be placed, while select surveillance would occur across a wider area (e.g. social and biodiversity observations). The choice of the core sites is based on their representivity of the natural and human-altered ecosystems typical of the broader Fynbos region and their suitability to allow comparative analyses of the biophysical, ecological and social mechanisms that drive critical ecosystem resources (e.g. water, carbon, nitrogen, energy, biodiversity, materials etc) in this region and possibly to track the impact of strategic interventions (e.g. restoration and protection of ecological infrastructure). They also build on existing data sets and the partner networks, described below. We acknowledge that the final siting of EFTEON instrumentation and other observations will need to be refined once the list of EFTEON instruments, sampling design and national objectives are known, but would like to highlight that our proposed landscape offers a lot of flexibility as there are many very good sites.

We propose that the core EFTEON observations be focused on several catchments within Greater Cape Town that complement existing research and monitoring initiatives (see **Map 1**). This maximizes the combined coverage by filling gaps in the partner networks in the region, but is also designed such that the EFTEON site observations can stand alone. This set of core sites allow us to explore the mountain catchment - lower catchment to coast continuum, but also to make comparisons among mountain or lower catchments. This captures several key themes relevant to the Fynbos region and/or globally. Firstly, linking mountain catchments to the coast allows us to explore the various fluxes and drivers of biogeochemical cycles (water, nutrients, carbon, etc) along the catchment to coast continuum. Extension of the site to the coast also allows us to link this EFTEON site with the Shallow Marine and Coastal Research Infrastructure's (SMCRI) Two Oceans Sentinel Site, which will monitor the estuaries, coastline and nearshore marine environment, which are greatly influenced by processes in the catchments. Secondly, the mountain - lowland transition is a key characteristic of this and many other regions of the world, with different biota, ecological processes, and global change pressures. Our chosen catchments not only allow us to explore this transition, but the inclusion of multiple mountain and multiple lowland catchments allow us to compare how differences in social and biophysical settings or global change drivers determine the trajectories of upland or lowland ecosystems. Third, by making the urban component of this landscape an intrinsic feature of the LTSER, this platform is well positioned to begin to interrogate some of the social-ecological dynamics representative of the challenges faced by many southern African cities, e.g. increasing water scarcity, rapid land cover change and pervasive social inequalities. By exploring connectivity between the City and its hinterland, e.g. the City's reliance on external water resources, and the particular governmental landscape planning as manifested in this region, the various proposed nested scales of social-ecological research are aligned to a scale relevant to regional planning and implementation frameworks.

Our proposed core areas have been delineated using quaternary catchment boundaries, but are mostly restricted to smaller portions of these larger catchments as described below. The core areas are also extensible, with flexibility to expand or contract their extent to match capacity and other resource constraints.




***Map 1.*** *The Greater Cape Town region, highlighting the quaternary catchments that contain the core of the proposed EFTEON landscape (red) and existing partner networks that contribute to the GCT-LTSER, including SAEON and the Greater Cape Town Water Fund (GCTWF) priority catchments. Note that H60A is shared between the GCM EFTEON proposal and the GCTWF, while most catchments are shared with the City of Cape Town and Department of Water & Sanitation.*

## The proposed core areas

- *Upper Catchments:* These are G40C, G40A, H60A. While it remains to be workshopped, current indications are that the biggest focus in these catchments will be on developing a relatively dense meteorological network as this, combined with Jonkershoek and other partner instrumentation would afford spatially continuous monitoring of climatic conditions across the core of the Boland Mountains, one of the most important Strategic Water Source Areas in the country (Nel et al. 2017). This provides a robust backdrop for exploring climate and weather effects on surface and groundwater dynamics, in addition to the role of climate and climate change in determining the current and future distribution of the extreme biodiversity contained in these mountains. These mountain catchments also provide the landscape with two long elevational transects with road access to Hansekop (1200m) and the Landdroskop mountain huts (1100m). The dominant land cover in our focal areas of these mountain catchments is natural Fynbos and indigenous Forest, but land cover/use pressures include plantation forestry (mostly exit areas), invasive alien trees, and groundwater abstraction from the Table Mountain Group Aquifer. We may seek to gauge streamflow on the Wesselsgat, Palmiet and Riviersonderend before they enter the Eikenhof, Nuweberg and Theewaterskloof Dams respectively.
    - G40A is the Steenbras catchment. Within the catchment we would focus on the upper portion, North of the N2, to complement the extensive hydrometeorological network run by the City of Cape Town below the N2 (including surface and groundwater) around the Steenbras dams and wellfield. We may extend some monitoring into the lower catchment to consolidate a complete gradient along the Steenbras river from mountain catchment to coast.
    - G40C is the catchment of the Wesselsgat and Palmiet rivers in the Hottentots-Holland. We currently propose working in the upper catchment down to where the two rivers feed into the Eikenhof dam to the North (and upstream of) the town of Grabouw. Should resources allow, this could be expanded to include the rest of the quaternary catchment, including the southwestern slopes of Groenlandberg to Applethwaite Lake, below and

South of Grabouw. This catchment includes extensive groundwater monitoring as part of the new Nuweberg wellfield being developed by the City of Cape Town. Lower in the catchment, agriculture mainly takes place in the form of commercial permanent orchards of apple, pear and wine grapes. There are also smaller portions of planted pasture. Groundwater monitoring of the long term impacts of fertilizer and pesticides are therefore important in this catchment, should we extend below Eikenhof dam.

    - H60A is the upper catchment of the Riviersonderend from source to Theewaterskloof Dam. This catchment is critical in feeding Theewaterskloof Dam and includes some groundwater monitoring as part of the Nuweberg well field. Including this catchment also allows us to link G40A&C into one continuous unit combining the existing SAEON infrastructure at Jonkershoek (G22F) and Greater Cape Town Water Fund monitoring around Theewaterskloof (H60B) and the upper Berg (G10A).

- *Lower Catchments:* These are G22H, G22E, G22D, G22G and are predominantly chosen to reflect different dominant land use and land cover (see **Map 3** and **Figure 1**), varying degrees of modification of the surface water systems, and linkages with the Cape Flats Sand Aquifer - another major resource for bulk water supply for the City, but with substantial contamination issues. G22H, G22E and G22G also combine with G22F (Jonkershoek) to form a full upper catchment to coastline unit, while G22D and G20A (Steenbras) each achieve this on their own.
    - G22H is the catchment draining into the Eerste River (fed by G22F - Jonkershoek) and finally into False Bay. It is predominantly cultivated agriculture, with smaller portions of natural and alien vegetation and built up areas.
    - G22E is predominantly built up with middle to low income housing and informal settlement. It drains into the heavily modified and canalized Kuils River, which leads into substantial wetland systems and finally joins the Eerste (G22H) before flowing into False Bay.
    - G22G Is largely cultivated land, but also contains some natural and much of the town of Stellenbosch. It drains into the Krom and Plankenburg rivers,

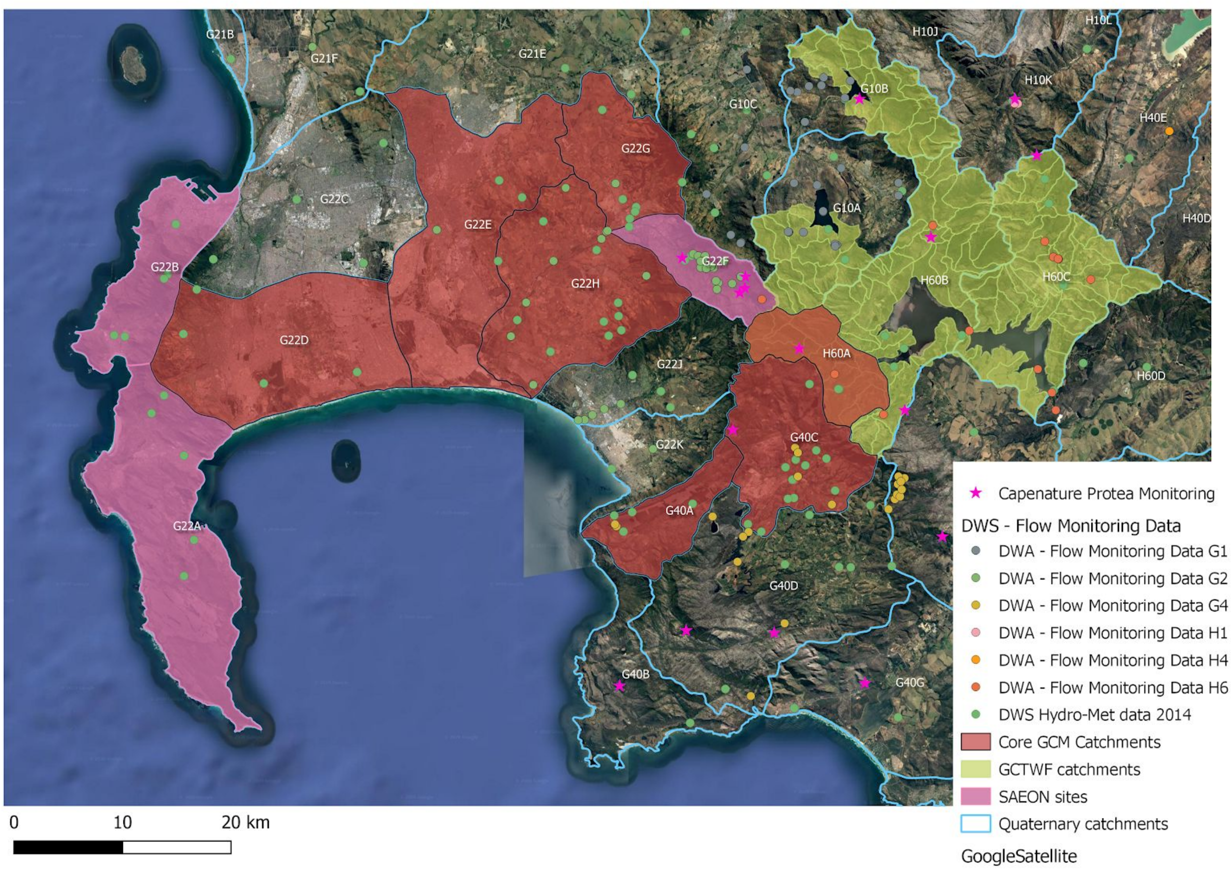
which meet in Stellenbosch and flow into the Eerste as it comes out of G22F (Jonkershoek). Should we need to scale back the size of the landscape this catchment could possibly be eliminated by only monitoring its inputs into the Eerste River.

- G22D is not linked to the Eerste mountain to coast gradient, but would be desirable to include for several reasons. Firstly, it differs from the other lowland catchments in that it contains a high proportion of built up areas, with a gradient from high, through middle to lower income and ultimately informal settlement that is characteristic of urban settlement in South Africa. This site has the advantage of this gradient playing out, for the most part, across a uniform soil and vegetation type, allowing for effective comparative and ecological change research across a social gradient. Secondly, the eastern portion of this catchment contains a large portion of the Cape Flats Sand Aquifer. Lastly, it links the landscape from existing SAEON and SANParks observations on the Cape Peninsula to the Boland mountains, and allows a third catchment to coast continuum (starting in the Table Mountain Chain). Note that this catchment is an amalgamation of a number of drainage and surface water systems (e.g. Diep, Sand and Lotus), with some linked via the Cape Flats Sand Aquifer, while others may not be. It is unlikely that all of them would be monitored as part of this landscape.

## Partner networks

Beyond the core sites for the GCT-LTSER landscape it is important to view this proposal in light of the network of existing initiatives and observations run by landscape partners in the surrounding catchments (**Map 2**). Together, this will contribute to the understanding of the functioning of the entire system. The adjacent G22F catchment contains the Jonkershoek valley, which has a long history of environmental monitoring and research and is currently a core site of the SAEON Fynbos Node, hosting a dense network of hydrometeorological instrumentation, including an eddy covariance system (https://fynbos.saeon.ac.za/authors/jonkershoek/). Several of the other adjacent catchments (and partially overlapping with the core EFTEON site in H60A) are the focus of The Greater Cape Town Water Fund, a long-term (30+ year) partnership coordinated by The

Nature Conservancy to secure water provisioning through removal of invasive alien plants and restoration of catchments financed by downstream users (e.g. municipalities) and donors (GCTWF; Stafford et al. 2019). This, combined with further alien clearing efforts and observations by the City of Cape Town and CapeNature in G40C and the lower portion of G40A provides a unique and rich opportunity to measure the impacts of invasive alien species (IAS) and the management of IAS in a water stressed environment. Furthermore, the City's groundwater monitoring in these catchments provide the opportunity to explore groundwater dynamics, recharge, flowpaths and the interactions between surface and groundwater in the Table Mountain Group Aquifer (TMGA).




***Map 2***. *Existing catchment monitoring infrastructure in and surrounding GCM-LTER landscape. This map is not comprehensive nor fully up to date but does illustrate the relative situation of the instrumentation. Please also see [https://fynbos.saeon.ac.za/dashboards/efteon/](https://fynbos.saeon.ac.za/dashboards/efteon/) for an interactive view of existing hydrological, meteorological and vegetation survey observations in this landscape.*

This landscape will also leverage the considerable data collected by the City of Cape Town in the lower catchments, including air quality, water quality and flow rates (surface and groundwater), extensive biodiversity observations and much more. There are also a large number of other research and observations being performed in the landscape, which have great potential to contribute to the site, including the South African Weather Service (SAWS), the Agricultural Research Council (ARC), the National Department of Wate and Sanitation, farmers associations and many others. Lastly, the SAEON Fynbos Node and SANParks have extensive biodiversity and meteorological observations on the Cape Peninsula (G22B and G22A; https://fynbos.saeon.ac.za/authors/capepeninsula/). See the section on existing observations, experiments and research for more.

## Scalability

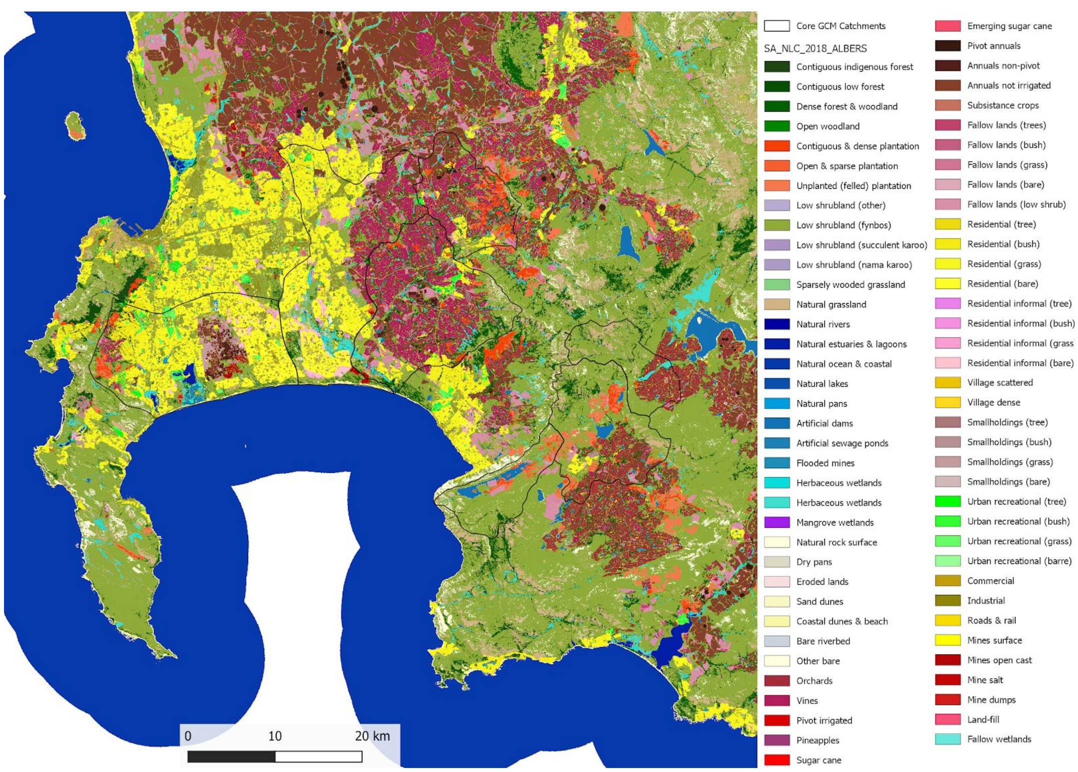
The structure of this proposal is premised on the ability for the methods and information collected to be scalable in several different non-exclusive ways:

- by assessing the information at different spatial and temporal scales, which shows the inherent hierarchically nested scales at which we intend to work (see Sections on Spatial Extent, Coupled terrestrial, Societal context and opportunity to observe social-ecological systems and aquatic systems and Strategic Water Source Areas)
- by potentially utilising mobile instrumentation that can move from site to site, should EFTEON and all parties agree (see Section on Suitability for the deployment of micrometeorological observations)
- by leveraging the extensive set of networked partners that have indicated support for this proposal, including higher education institutions and their students

There is also great potential to adjust the scale and extent of the landscape proposed to match the available EFTEON and partner resources, as suggested in the catchment descriptions for the proposed core areas above. Ultimately, we are cognisant that we will need to make sure that the respective roles and responsibilities of the EFTEON team and partner organizations for maintaining the various observations in different parts of the landscape are clear, and that the majority of EFTEON's contribution forms a coherent set of observations independent of the partner networks.

## Significant land uses

The landscape covers the full array of major classes as classified by the South African National Land-Cover 2018 (DEA 2018), which extends from completely natural areas to increasing amounts of cultivation and urbanisation (see **Map 3** and **Figure 1**). The relative proportions of the different major land cover types differ substantially between the lowland and upland catchments, but also among lowland and upland catchments, allowing potential for intercomparisons. There are also interesting differences within the major land cover classes, such as the income status of the residential areas within the "Built up" class, or whether the "Cultivated" land is irrigated (typically vineyard or orchard) or not (typically grain crops or pastures). The breakdown of dominant land cover by quaternary catchment is given above under "The proposed core areas" above, and further details in relation to key challenges and research needs in "The landscape location in the face of global change".



***Map 3.*** *Land use classification of the core Greater Cape Metro landscape based on the 2018 South African National Land-Cover (DEA 2018).*

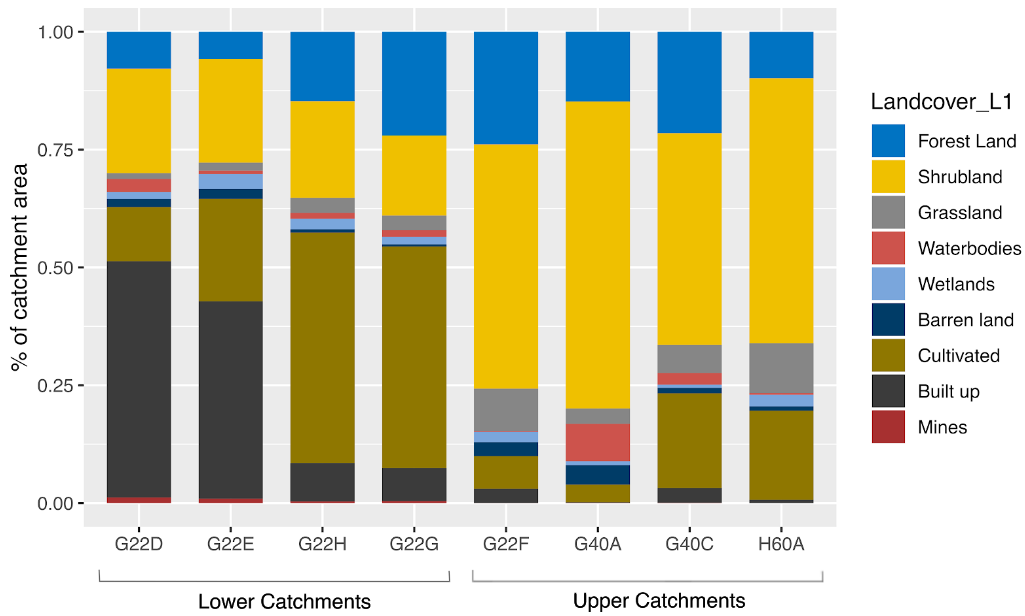



***Figure 1:*** *Comparison of the percentage area for each land cover class (Level 1) within each catchment based on the Department of Environmental Affairs' South African National Landcover 2018 dataset. Catchments have been divided into lower and upper catchments. *Note, G22G is is a mix of upper and lower, feeding into the Eerste catchment (G22H).*

# Suitability of the landscape to meet the requirements of the EFTEON Research Infrastructure

Note: We explicitly have not highlighted questions in this section, because deciding the important, overarching questions that this research landscape aims to address needs to adhere to a process of discussion and co-production. We do provide a summary of some of the proposed scientific and societal objectives at the end of the proposal. A list of potential questions would be endless.

## The general situational characteristics of the landscape

### Significance of the landscape

The details of the features of particular significance in this landscape are elaborated on in more detail in the sections that follow, but here we provide a brief summary of the features requested in the proposal solicitation.

#### Strategic Water Source Areas

The proposed landscape intersects with four surface and groundwater SWSAs (Le Maitre et al., (2018), with the core site encompassing a portion of the Boland surface water SWSA, the Cape Peninsula and Cape Flats groundwater SWSA, and the Southwestern Cape groundwater SWSA. The network of partner sites that make up the greater landscape increase the coverage of these three SWSAs and add the Table Mountain surface water SWSA. All of these SWSAs are of critical importance for current and future bulk water supply for the region and are linked to ecosystems that are both under threat and harbor exceptionally high global biodiversity value. This offers the opportunity to explore multiple nested and highly complex social ecological systems in the landscape (Brill, Anderson, and O'Farrell 2017b; Nel et al. 2017). One of the issues this proposed landscape hopes to address is the paucity of high elevation meteorological data in these SWSAs, which is a key requirement for almost all research and attempts to manage the benefits from the SWSAs sustainably.

**Biodiversity hotspots, endemism and phylogenetic diversity**

The landscape falls within the Cape Floristic Region (CFR) Global Biodiversity Hotspot (Myers et al. 2000), containing approximately 9000 plant species, of which more than two thirds are endemic (Manning and Goldblatt 2012). Within the CFR, the core site encompasses the majority of the diversity of the Southwestern centre of plant endemism, while the partner network also includes the Cape Peninsula centre (Goldblatt and Manning 2000; Freiberg and Manning 2013), comprising upwards of 4000 vascular plant species. The CFR represents significant globally unique plant phylogenetic diversity and is the most dissimilar to the flora of the rest of Southern Africa according to the phytogeographic zones recognized by Daru et al. (2016) on the basis of the phylogeny of the woody flora.

The GCT-LTSER landscape is an area representative of high animal endemism, particularly amongst amphibians (Turner & de Villiers 2017), terrestrial insects (Kemp and Ellis 2017; J. S. Pryke and Samways 2008), freshwater fish (Impson et al., 2017) and freshwater invertebrates (Mlambo et al. 2011). It also hosts six of the seven CFR endemic bird species. The evolutionary processes that have driven the exceptional speciation in both plants and animals are well illustrated in this area and will be instructive for understanding responses to climate change and the future for this biodiversity.

**Carbon sequestration potential**

The Fynbos is considered to have the third highest carbon stored per $m^2$ ($gC.m^2$) for any biome in South Africa, after Forest (small patches of which occur in the landscape) and Albany Thicket ("The South African Carbon Sinks Atlas, First Edition" 2017). That said, there is very little literature on the topic from the region. That which exists largely focuses on pools and ignores fluxes. They suggest that conversion of natural Fynbos to other land cover types may result in little change (pastures and vineyards; Mills et al. 2012) or minor gains (exotic timber plantations; Chisholm 2010) in total ecosystem organic carbon, but that the costs to other ecosystem services (e.g. water) or disservices (e.g. fire) may not be acceptable. Within natural vegetation, there is evidence that local exclusion of fire is driving transitions from Fynbos to Forest biome, where soils and climate are otherwise amenable (Slingsby et al. 2020; Cramer et al. 2018). The impact of increased atmospheric $CO_2$ on Fynbos ecology and processes is not well understood and has not been well explored. Species in the biome predominantly utilize the $C_3$ photosynthetic pathway and should be expected to respond to elevated $CO_2$, but any $CO_2$ fertilization effect may be limited by the poor soil nutrient status (Guy Midgley *pers comm.*). By extension, if there is a $CO_2$ fertilization effect in Fynbos it may be more pronounced in areas with higher atmospheric N deposition (assuming N is the limiting nutrient). Interestingly, correlative studies based on satellite derived measures of productivity suggest that Fynbos vegetation growth rates increase with higher minimum winter temperatures, suggesting that we may see faster biomass accumulation, and potentially shorter fire return intervals, as temperatures increase with climate change (A. M. Wilson, Latimer, and Silander 2015; Slingsby, Moncrieff, and Wilson 2020). At finer scales, our proposed landscape includes several ecosystems that are considered to be significant potential carbon sinks, especially a vast diversity of wetland types, such as peat-forming palmiet wetlands (A. J. Rebelo et al. 2019). Further, there remain many uncertainties surrounding urban carbon fluxes and their effects on regional and global carbon budgets (Hutyra et al. 2014). Substantial work can be done to decrease uncertainty surrounding urban (and agricultural) carbon budgets by addressing accurate characterization of urban vegetation (which is often assumed homogeneous in larger scale studies) and its influence of C fluxes.

### Landscapes of high cultural value

Much of the landscape forms part of the Cape Floral Region Protected Areas UNESCO World Heritage Site. It also intersects with the Cape Winelands and Kogelberg UNESCO Biosphere Reserves, and includes the False Bay Nature Reserve Ramsar Site. The core site encompasses several provincial and municipal nature reserves, while the partner sites include Table Mountain National Park. The site has a long history of human occupation and modern humans have been present for almost 100 000 years, and early hominids before that, revealed by discoveries of hand axes made by *Homo erectus* approximately 750 000 years ago. The landscape also contains many sites of high historical value given that it is where European colonists first settled in southern Africa, which marked a sharp discontinuity in human-environment relations (Roberts, Meadows, and Dodson 2001). Nature in the metro today is variably engaged by the diversity of cultures that make up this typically heterogeneous African city (P. Anderson and O'Farrell 2012) and can be found entrenched in cultural, social and religious practice. It is also a landscape of high cultural value in terms of global tourism and is South Africa's premier tourist destination as a result of its spectacular natural beauty and cultural diversity.

**Areas of anticipated significant land use or social change**

The Cape Town city-region is the Western Cape's economic powerhouse, with its positioning in the global economy resting on its regionally strong tourism, food and beverage, and education and academic research sectors (Department of Environmental Affairs and Development Planning 2019). The bulk of the region's population lives in the City of Cape Town and the Cape Winelands (combined they make up ~ 5 million people), with an expected 0.9% year on year growth rate in the coming years (City of Cape Town 2017). Income inequality has been increasing in all districts of the Western Cape since 2010, although the rates of increase in the City of Cape Town and the Cape Winelands are lower than neighbouring districts. Urban efficiency and shared growth are highlighted to be regional imperatives, which will be dependent on the strength of education and academic research sectors, in addition to tourism and the food and beverage industry. The strength of the city-regions tourism and agriculture sectors and its connectivity to the global economy rely heavily on the region's biodiversity and water assets, both of which have been identified in the National Development Plan (National Planning Commission 2011) as 'critical resources' that underpin the region's economic activity. Taken together, we are likely to see significant changes in the way in which the land is used over the next 20 years as the population, which bears a heavy and complex burden of historical social injustice and inequality, increases and either densifies (officially) or spreads (informally) at a cost to agricultural and near-natural (biodiversity supporting) lands (Allsopp et al. 2014) .

Other natural resources are likely to see similar challenges. Water and biodiversity are under significant threat from a number of interacting global change drivers, but perhaps most alarming are the heavy infestations of invasive alien plants in the Strategic Water Source Areas (the mountain catchments and aquifers), which are having a significant impact on both biodiversity and bulk water supply (Van Wilgen and Wilson 2018; Le Maitre et al. 2019). Efforts by the Greater Cape Town Water Fund and others to provide sustainable water yields for current and future generations by establishing a governance and funding mechanism to restore these Strategic Water Source Areas will be crucial in this regard (Stafford et al. 2019). Another ray of hope is the City of Cape Town's Water Strategy (CoCT, 2019), which represents a significant paradigm shift in the way urban water resources are managed. The commitment to improving access and quality of service to informal settlements and low-income areas; optimising the economic, social and ecological benefits of regional water resources; and transitioning to a Water Sensitive City requires a holistic, systems-thinking approach to how water and related environmental resources are managed. This is no small task and will require input from the City, local communities and organisations, NGOs, academic institutions, consultants and land managers. This provides for an exciting, vibrant and potentially impactful research space, and has potential to catalyse a sea change in the way natural resources in the region are managed.

**Catchment to coast continua (and links to other SARIR projects)**

Our landscape links >1500 m peaks to the ocean, and includes interactions with two major aquifer systems. Linking this landscape to the Two Oceans Sentinel Site of the Shallow Marine and Coastal Research Infrastructure (SMCRI; https://smcri.saeon.ac.za/) offers the opportunity to observe and explore most components of the major biogeochemical cycles (water, carbon, nitrogen and other major nutrients and/or chemical elements) and their interactions with the unique biodiversity and social ecological systems of the region. Our partnership with the isotope (University of Cape Town) and water & soil (Stellenbosch University) nodes of the Biogeochemistry Research Infrastructure Platform (BIOGRIP) within the landscape is a further strength in this regard. Lastly, we understand that the South African Population Research Infrastructure Network (SAPRIN) intends to begin developing their Cape Town Surveillance through Healthcare Action Research Project (C-SHARP) node at Nomzamo and Bishop Lavis in 2021, providing the opportunity to link to a fourth SARIR project.

### Elevation transects

The proposed core site includes two long elevational transects, with road access to Hansekop (1200m) and the Landdroskop mountain huts (1100m), and there are a number of others within the immediate broader landscape (e.g. Clayton's Road (from Constantia Nek to the dams on; 750m); Constantiaberg Peak (900m)), before one begins to consider hiking options.

## Unique biodiversity

*Mountain fynbos vegetation in the Jonkershoek catchment (Photo: Martina Treurnicht)*

### Terrestrial vegetation

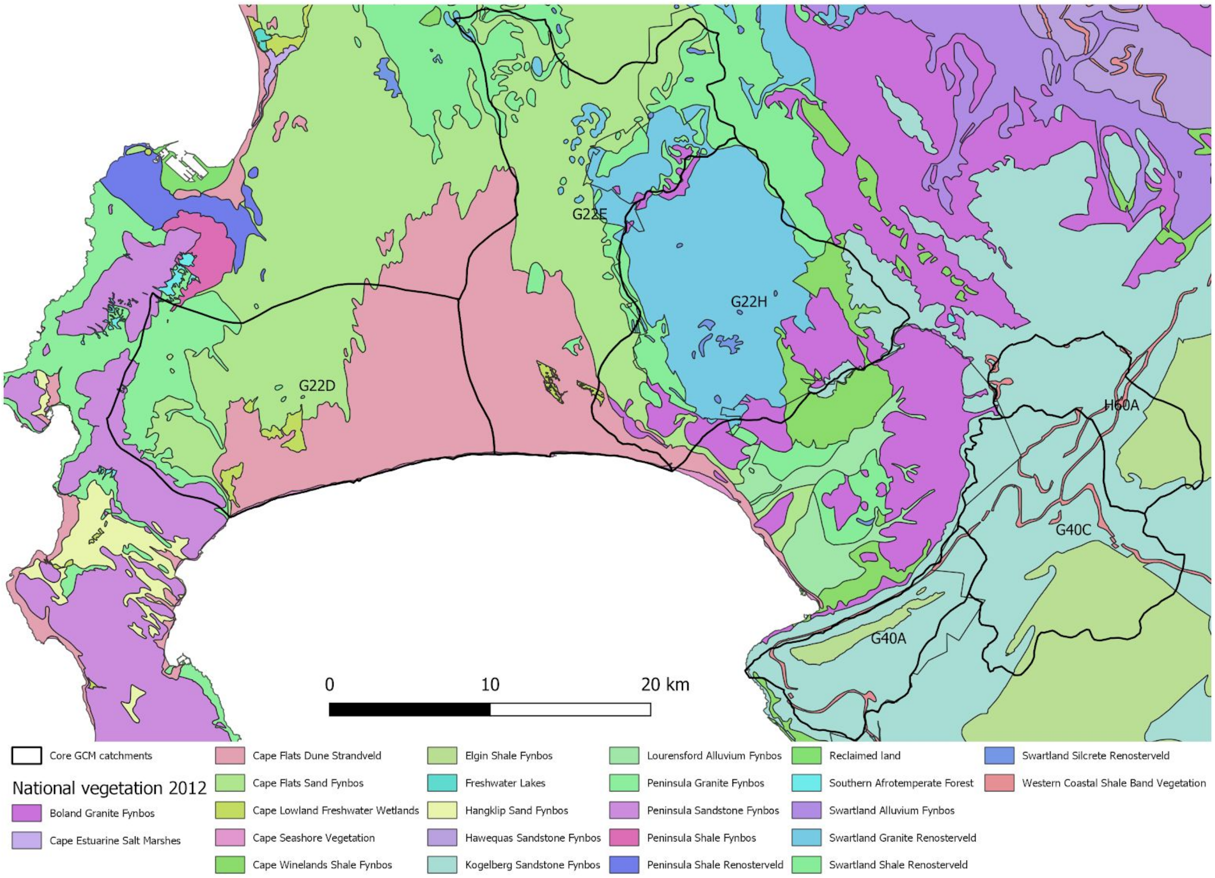
The proposed landscape covers a key part of the Cape Floristic Region (CFR), which is recognised as a global biodiversity hotspot (Myers et al. 2000), with both the Boland and Cape Peninsula being centres of diversity and endemism within the greater CFR hotpot

(Linder 2003; Freiberg and Manning 2013). Although the original global biodiversity hotspots were based on plant diversity alone (Myers 1990), more recent revisions (Myers et al. 2000; Mittermeier et al. 2011) show recognition of the growing appreciation of the animal diversity and endemism within this area (Procheş and Cowling 2006; Heideman et al. 2011; A. Turner and Channing 2017; Kemp and Ellis 2017). The primary constituent at a biome level in the CFR is the Fynbos Biome, which is known for its very high beta and gamma diversity (Latimer, Silander, and Cowling 2005; A. G. Rebelo et al. 2006). This turnover in species across the various geological and soil gradients, elevation gradients and local climate gradients reveals the evolutionary processes that have shaped the vegetation (Linder 2003) and now frame the novel challenges posed by a rapidly changing environment, largely driven by anthropogenic activity (Slingsby et al. 2014). The landscape includes all three major vegetation formations in the Fynbos Biome; namely fynbos (predominant in the uplands), and the lowland renosterveld and strandveld, which differ in structure, composition and function, largely due to different abiotic conditions (soils, climate) and disturbance regimes (fire, herbivory). These vegetation formations differ in the relative threat of the different major global change drivers. For example, they suffer different land use pressures due to desirability for agriculture, residential pressure (e.g. coastal development) and other factors; they're typically invaded by different alien plants with different impacts and legacy effects (P. Holmes et al. 2020); and are likely to differ in their response to climate change due to topoclimatic differences (Loarie et al. 2009). While the upland-lowland transition is largely driven by the stark geology/soil type differences there are also interesting cases that allow for a crossed design, such as shaleband fynbos vegetation that experiences the same climate as other mountain fynbos, but has more similar soil nutrients to lowland shale renosterveld. The landscape also includes numerous pockets of Forest Biome, which offer sharp (and often shifting) transitions from Fynbos driven by soil nutrients (Cramer et al. 2018), shading (Power et al. 2019) and fire (Geldenhuys 1994; Slingsby et al. 2020).

**Table 1**. Vegetation types represented in the GCT-LTER and their threat status as of 2018.

| Vegetation type | Threat category |
|---|---|
| Boland Granite Fynbos | **EN** |

| | |
|---|---|
| Cape Flats Dune Strandveld | **EN** |
| Cape Flats Sand Fynbos | **CR** |
| Cape Seashore Vegetation | **LC** |
| Cape Winelands Shale Fynbos | **VU** |
| Elgin Shale Fynbos | **CR** |
| Hangklip Sand Fynbos | **CR** |
| Hawequas Sandstone Fynbos | **LC** |
| Kogelberg Sandstone Fynbos | **CR** |
| Lourensford Alluvium Fynbos | **CR** |
| Peninsula Granite Fynbos | **CR** |
| Peninsula Sandstone Fynbos | **CR** |
| Peninsula Shale Fynbos | **VU** |
| Peninsula Shale Renosterveld | **CR** |
| Southern Afrotemperate Forest | **LC** |
| Swartland Alluvium Fynbos | **EN** |
| Swartland Granite Renosterveld | **EN** |
| Swartland Shale Renosterveld | **CR** |
| Swartland Silcrete Renosterveld | **CR** |
| Western Coastal Shale Band Vegetation | **LC** |




***Map 4.*** *Vegetation types according to the South African National Vegetation map (Mucina, Rutherford, and Others 2006; updated 2018) showing the great diversity of National Vegetation Types in this landscape.*

## Rivers and wetlands

The Cape Fold Ecoregion (hereafter CFE), which overlaps almost entirely with the CFR, of South Africa is one of the five aquatic ecoregions of southern Africa and incorporates the drainages that flow off the Cape Fold Mountains along the southern fringe of the African continent (Abell et al. 2008). The Greater Cape Town region falls entirely within the CFE and includes a rich variety of river and wetland ecosystems. Although best known for its vascular plant diversity and endemism, the CFE is home to an assemblage of range-restricted endemic freshwater fishes, and a high diversity of aquatic invertebrates.

*Rivers*

The upper catchments (G40C, G40A, H60A) include the Steenbras, upper Palmiet and upper Riviersonderend rivers. The Steenbras catchment (G40A) includes the Steenbras Nature Reserve which forms part of the greater Kogelberg Biosphere Reserve. The Steenbras dam is a major supply dam for the City of Cape Town. Historically the region had significant pine plantations.  The Palmiet and Wesselsgat rivers (G40C) arise in the Hottentots-Holland Mountains, where natural fynbos comprises approximately 45% of the catchment. Historically, pine plantations were prevalent in the upper reaches. Two major in-stream dams on the Palmiet River, the Nuweberg and Eikenhof, supply domestic and irrigation water respectively.  Both these dams exert a major control in the upper reaches as they have severely modified the flow patterns in the river.  Industrial, agricultural and domestic wastewater and runoff near Grabouw result in elevated organic loads in the river, causing eutrophication and low dissolved oxygen levels. The river health in the upper reaches, above the dams, is largely natural although it deteriorates substantially downstream of Grabouw. The upper catchment of the Riviersonderend (H60A), from source to Theewaterskloof Dam, is largely natural with a diversity of aquatic biota.

The lower catchments include largely transformed urban and agricultural catchments, with highly impacted rivers, river health and limited aquatic biodiversity. G22G comprises largely cultivated land, but also contains some natural and much of the town of Stellenbosch. It drains into the Krom and Plankenburg rivers, which meet in Stellenbosch and flow into the Eerste River (G22H). G22H is predominantly cultivated agriculture, with smaller portions of natural and alien vegetation and built up areas. Similarly, the heavily modified and canalised Kuils River (G22E) is predominantly built up with middle to low income housing and informal settlement. It drains into, which leads into substantial wetland systems and finally joins the Eerste (G22H) before flowing into False Bay. G22D includes Zandvlei and Rondevlei,  Zeekoevlei, all important wetland systems within the urban landscape.

*Wetlands*

The complex geology, history and topography of the Greater Cape Town area, and the remarkable diversity of vegetation types in the Fynbos Biome combine to drive wetland diversity upwards, in terms of types of wetlands, and the floral and faunal communities they support.  As in the rest of South Africa  (Ellery et al., 2009), the majority of the Cape wetlands are associated, in some way or another, with river systems.  Most are seasonal seeps on sandy and occasionally peaty soils, feeding into the area's rivers, some are floodplain and valley-bottom wetlands lying on valley floors and plains such as the Cape Flats, and others are the estuaries that tie the land to the sea.  Interestingly, the largest urban wetland in the Greater Cape Town area is the Zeekoevlei/Rondevlei complex, also a Ramsar site, and the nearby Rondevlei wetland is home to the only relatively wild hippopotami in the south-western Cape.

Wetlands in the area are fed by rainfall and river discharge, with groundwater also playing an important role, either from shallow short return-time interflow in the vadose (unsaturated) zone, or from the deeper long return-time aquifers  (Snaddon et al., 2014; Snaddon et al., 2018), especially for peatlands.  It was previously thought that there were few peatlands in the south Western Cape, but recently it has been shown that there are several important peatlands in the sub-region (Grundling et al., 2017) . Most of these wetlands are dominated by the palmiet plant, *Prionium serratum*, an important plant (in combination with the peaty soils) for stabilisation of channels, sediment accumulation, and streamflow regulation (e.g. A. J. Rebelo et al. 2019).  The palmiet peatlands of the sub-region are also important for carbon storage.

Wetlands are vital for the sub-region's water security (Snaddon et al., 2018), and yet nationally they are the most threatened and least protected ecosystems (van Deventer et al. 2020).  Wetlands are vulnerable to climate change (to varying degrees), and to degradation that will reduce their efficiency in responding to the impacts of climate change, and the extent to which they provide essential ecosystem services to human beings.

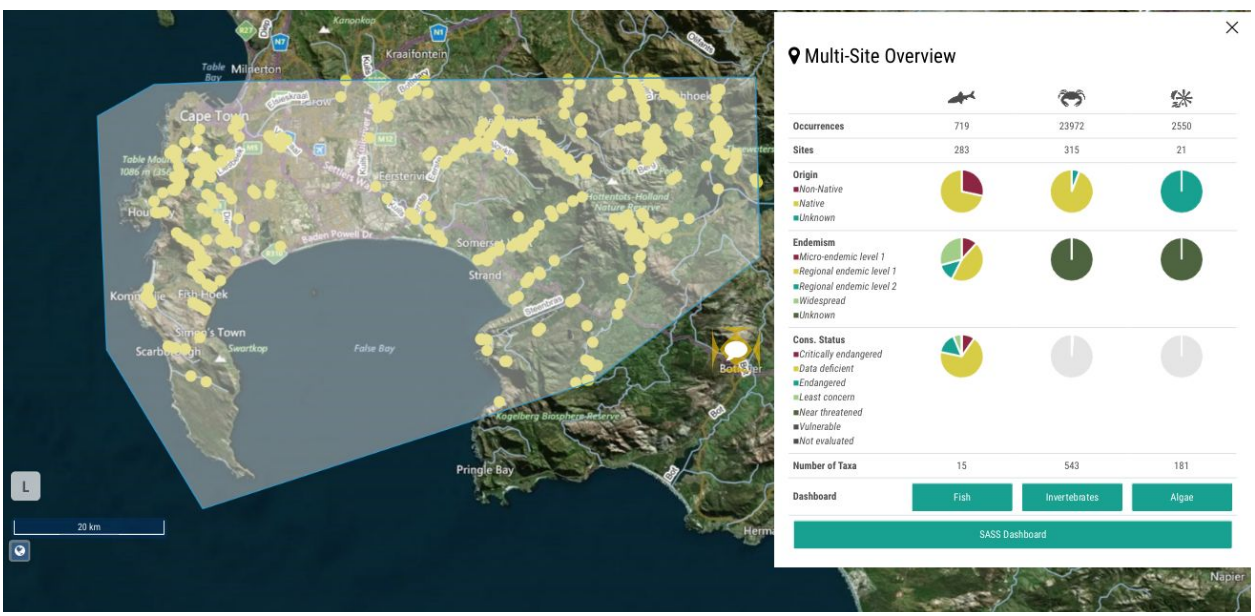
**Aquatic fauna**

The freshwater fish fauna of the CFE is characterized by low species diversity (23 species formally-described), and high endemism (20 species) (B. R. Ellender and Wasserman 2017), and the majority of these taxa are high conservation priorities and are under severe threat of extinction (Ellender et al., 2017). Fourteen of the 20 fishes endemic to the CFE are currently evaluated as Vulnerable, Endangered or Critically Endangered using International Union for Conservation of Nature (IUCN) Red-List criteria (Weyl et al. 2014; Da Costa et al., 2009). In terms of the focal catchments for this proposal, there are four species of native freshwater fish in the Berg Catchment (*Pseudobarbus burgi*, *Sandelia capensis*, *Galaxias zebratus* and *Pseudobarbus capensis*), and five in the upper Breede and Sonderend Catchments (*Pseudobarbus burchelli*, *Pseudobarbus skeltoni*, *Sandelia capensis*, *Galaxias zebratus* and *Pseudobarbus capensis*).The Berg-Breede River Whitefish (*Pseudobarbus capensis*) is considered locally extinct in the Berg River. If one considers genetically distinct lineages (still to be formally described as separate species), then the number of taxa in the Breede/Sonderend catchment goes up to 14 (Ellender et al., 2017). All of these taxa are regional endemics and some have very narrow distribution ranges.

*The Breede River redfin - endemic to the Breede River catchment (Photo:  Jeremy Shelton)*

Recent biogeographic and taxonomic research in the CFE using molecular techniques has revealed that the region’s freshwater fish diversity has been severely underestimated. The consequence is that species previously thought of as widespread are now being split into species complexes consisting of a number of genetically unique lineages, many of which are limited to single systems, streams or reaches of streams (B. R. Ellender and Wasserman 2017). To date there are 42 recognized taxa of which the majority (~60%) are on the IUCN Red List as either Endangered or Critically Endangered (Ellender et al., 2017). A further fifteen non-native freshwater fish species have established populations in the CFE region as a result of introductions for angling and aquaculture over the last two centuries (Bruce R. Ellender and Weyl 2014; I. J. De Moor 1988).

The region is home to at least 796 species of aquatic invertebrate , of which approximately two thirds are endemic to the region  (F. C. De Moor and Day 2013). There are at least 175 taxa of freshwater invertebrates in the Greater Cape Town Metro Area (FBIS, 2020), but the actual number is expected to be notably higher.  Threat status of these taxa is largely unknown, and Red-List assessments of the region's aquatic invertebrates has been identified as a priority by SANBI. Human-linked impacts including the introduction of non-native species, water abstraction and climate change impacts, have resulted in widespread aquatic ecosystem degradation and dramatic decreases in the distribution, range and abundance of many of its freshwater taxa over the last century (Tweddle et al., 2009).




*Extract from the Freshwater Biodiversity Information System ([freshwaterbiodiversity.org](freshwaterbiodiversity.org)) for the proposed landscape (including partner sites) showing diversity and occurrence records of freshwater fish, invertebrates and algae in the database.*

### Terrestrial fauna

Around 200 species of birds occur regularly with the proposed landscape area, of which 39 are endemic and 15 near-endemic to southern Africa. Most significantly, the landscape contains species belonging to two families that are endemic to South Africa, namely the Cape Rockjumper (*Chaetops frenatus*) and the Cape Sugarbird (*Promerops cafer*). Endemic species such as these are a major draw for avifaunal tourism as they represent the unique evolutionary history of the area. With the FitzPatrick Institute of African Ornithology situated at the University of Cape Town, this area is a hub for ornithological research on the continent. In addition, long-term and large-scale monitoring of South Africa's avifauna has been made possible through citizen science projects like the South African Bird Atlas Project (SABAP2), or the long term Coordinated WAterbird Counts (CWAC). Data from SABAP2 have begun to reveal trends such as range expansions and contractions, changes in migration patterns and declines in certain species. Interpretation of these trends would benefit from accompanying landscape-level data to ascertain the drivers behind these changes, as birds may be responding to changes in rainfall seasonality, urban heat island effects, vegetation cover or alien species.

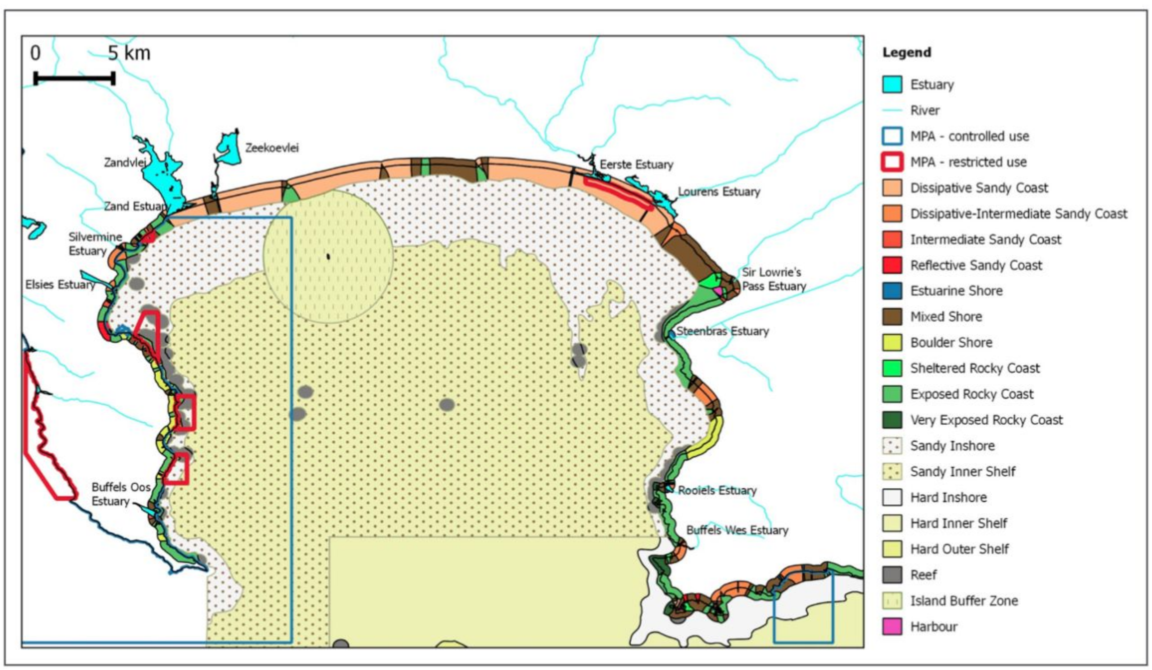
The landscape has 26 frog species of which five are endemic to the GCT-LTSER region. There are at least 51 terrestrial reptile species recorded in the landscape. This is a high herpetofaunal diversity for a small temperate area compared to the 17 amphibian and 34 reptile species in Portugal (Loureiro et al., (2008). Of the 26 frog species, three are listed as Critically Endangered and two as Endangered *(*IUCN & SA-Frog 2016) indicating severe threats to the amphibian fauna in this area.

Despite the local extinction of several large mammal species, there are still 22 indigenous medium and large mammals as recorded in 12 reserves within the City of Cape Town boundaries by Schnetler et al. (2020). It is remarkable that some of the larger predators such as caracal and leopard still persist in this area. There are also many small mammals, although a systematic survey has not been conducted. It is likely that some of these species may be negatively influenced by climate change (Taylor et al. 2017) and conservation of mammalian diversity in the region may be quite challenging (Schnetler et al. 2020).

There are no known published figures enumerating the complete invertebrate diversity of the landscape or any proxy for this region. The studies that have been done in the area on particular taxa indicate high species richness (alpha diversity)  e.g. (e.g. James S. Pryke and Samways 2009; Kemp and Ellis 2017) and high beta diversity for some taxa (e.g. Janion-Scheepers and Griffiths 2020; Kemp, Linder, and Ellis 2017). There remains much work to be done to complete our understanding of invertebrate richness and ecological functioning in this area.

### Coastal, estuarine and marine biodiversity

While the focus of the EFTEON landscape is on terrestrial and freshwater ecosystems, a major feature of our proposed landscape is the continuum from the mountain catchments to the marine environment. Fortunately, much of the coastal and marine research in False Bay has recently been reviewed by Pfaff et al. (2019) showing that the diversity, function and socio-economic importance of the estuarine, coastal and marine ecosystems are not overshadowed by their terrestrial and freshwater counterparts.




***Map 5.*** *Benthic and coastal habitat map for False Bay (taken from Pfaff et al. 2019). https://doi.org/10.1525/elementa.367.f8*

*Kogelberg mountains and False Bay, looking South from Steenbras (Photo: Andrew Turner)*

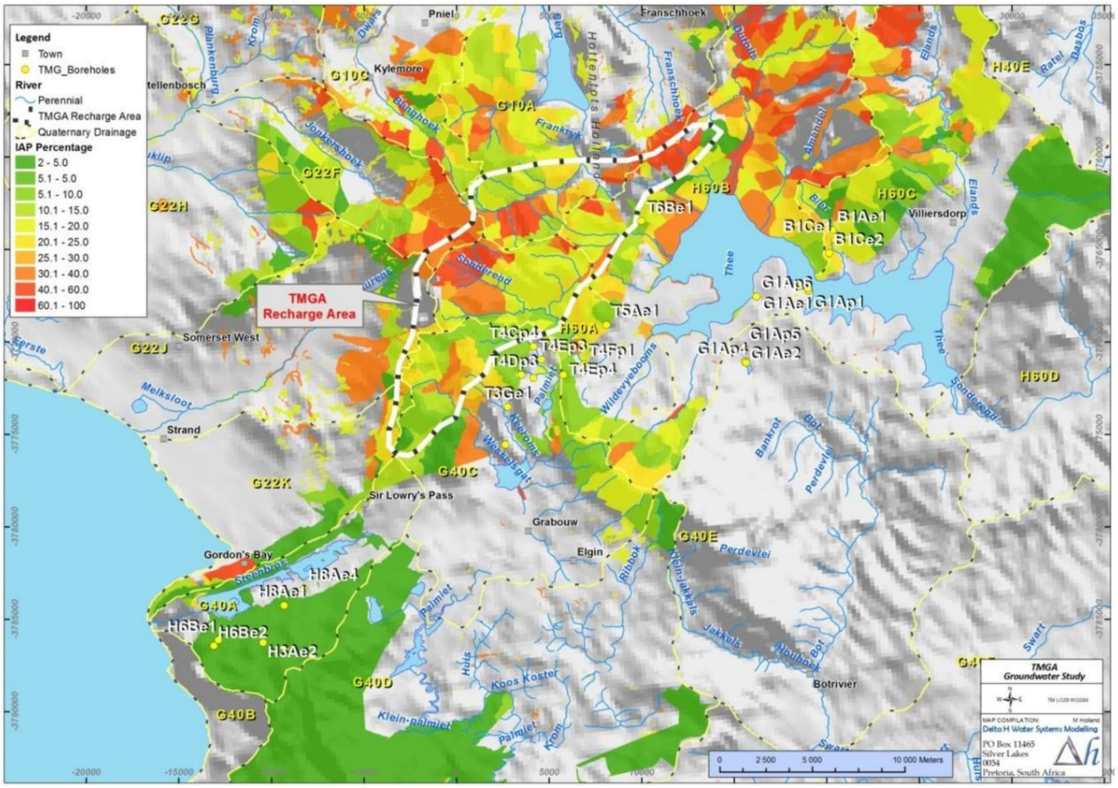
## Coupled terrestrial and aquatic systems

**Catchment to Coast: A continuum of nested and interacting systems.**

This landscape offers the opportunity to examine coupled terrestrial and aquatic systems along a catchment to coast continuum, from near-natural mountain catchments through low lying urban catchments to False Bay. While the distance travelled between these upper catchments and the coast is short (20-40 km), the longitudinal, lateral and vertical variability of these catchments (sensu Kaushal and Belt 2012) allows us to explore the biophysical setting and socio-ecological patterns and processes that ultimately drive these coupled systems. We can begin by focusing on the interactions between the social (e.g. demographics, technology, economy, culture, governance systems) and ecological (e.g. primary production, nutrients fluxes, biodiversity, organic matter) components of these systems (sensu Redman, Grove, and Kuby 2004) and how they differ at various points or change over time. Understanding changes in the flow of freshwater, sediments, nutrients and contaminants along the continuum and identifying the drivers and timescales of this change will be greatly facilitated by looking at these coupled aquatic/terrestrial ecosystems as social-ecological systems in their own right.

*Boland: Mountain Catchments*

The Boland Mountains is the highest rainfall area for both the Berg and Breede Water Management Areas, with rainfall up to 3345 mm/a (Bailey and Pitman, 2016), and produces the majority of the runoff and groundwater recharge in these areas (Watson et al. 2020). They support >8% of South Africa's population and contribute >11% of the country's gross value added (GVA; Nel et al. 2017). The upper catchments in our proposed core area feed into the Steenbras or the Theewaterskloof reservoir, which make up two of the 'Big Six' reservoirs that comprise the Western Cape Water Supply System (WCWSS), while our partner sites add catchments of the Berg River Dam. Our core catchments contribute significant recharge to the fractured rock Table Mountain Group Aquifer (TMGA; **Map 6**), but also include major wellfields developed by the City of Cape Town to augment bulk water supply (City of Cape Town 2019). There are large uncertainties regarding surface/groundwater interactions of this system, including the degree to which recharge is coupled to immediate aboveground rainfall and runoff (as opposed to catchments further afield), groundwater volumes and residence times (Miller et al. 2017), and the degree to which the hyperdiverse surface ecosystems depend on groundwater for their persistence (e.g. February et al. 2004). This is not aided by the paucity of high elevation meteorological data. As the region begins to develop greater dependence on the TMGA for bulk water supply, substantial monitoring and research is warranted.




***Map 6:*** *The main TMGA recharge area for the City of Cape Town's wellfields, overlain with estimated invasive alien plant coverage. To the best of our knowledge there are only two weather stations within the recharge area, at Dwarsberg (SAEON) and Landrosskop (ARC). (Figure taken from Turpie et al. 2018)*

While much of these catchments can be considered to be in a near-natural state, they harbor extensive and often dense stands of invasive alien tree species such as pines (*Pinus* spp), Black wattle (*Acacia mearnsii),* eucalypt *(Eucalyptus camaldulensis)* and Port Jackson willow *(Acacia saligna)*. The spread and density of these invasives can largely be attributed to these species escaping the extensive forestry plantations which dominated the upper part of the Steenbras (G40A) and mid-elevations of G40C (Palmiet and Wesselsgat). These plantations are now being cleared as part of the Western Cape forestry exit strategy and these "forestry exit areas" are either being adopted for conservation or their future is uncertain. Without due investment in restoration the unmanaged exit areas are very likely to revert to dense stands of pine trees.

*Pine trees in Suicide Gorge, Riviersonderend, Boland Mountains (Photo: ©Donovan Kirkwood)*

Invasive alien tree invasions have significant negative impacts on surface runoff (Le Maitre et al. 2019), and little is known about the impacts on groundwater recharge. Estimates of the impact of these alien species on the 98% assured yield of the WCWSS as of the year 2000 was a 6.6% reduction, and is expected to increase to a 22.3% reduction by 2045 without adequate intervention to manage the invasions (Le Maitre et al. 2019). This is equivalent to loss of yields of 38 million $m^3$ (the capacity of Wemmershoek Dam) to 130 million $m^3$ (the capacity of the Berg River Dam) per annum. In the context of the 2018 Day Zero, this would have provided an additional 54 to 185 days of water per year at 700 ML $d^{-1}$ (Le Maitre et al. 2019). This has spurred The Greater Cape Town Water Fund, a major public-private partnership aimed at restoring catchment ecological infrastructure and maintaining them in the long term, led by The Nature Conservancy (Stafford et al. 2019). Tracking the success or failure of this and other initiatives like the Department of

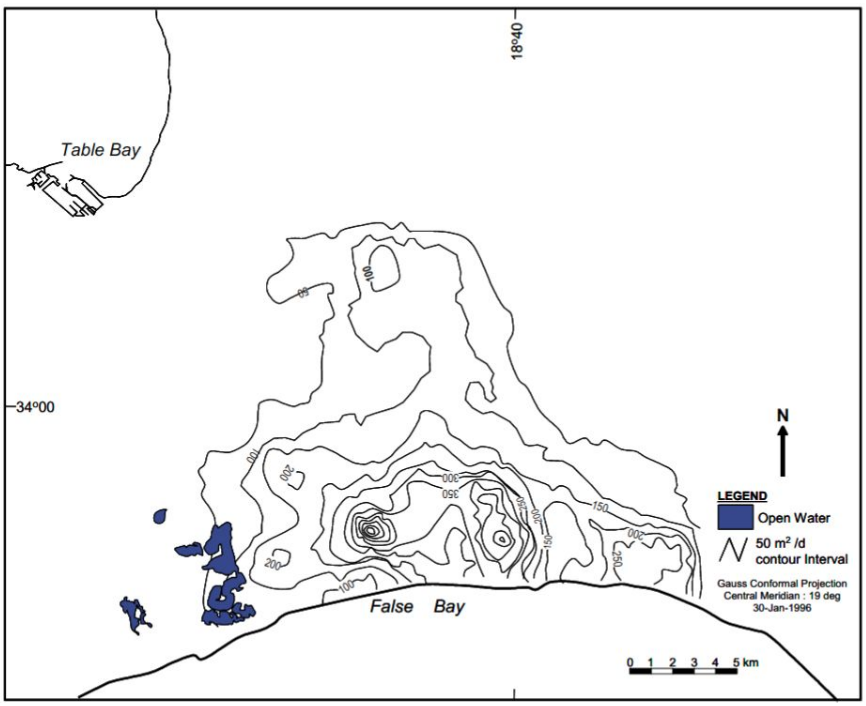
Environmental Affairs and Development Planning's Ecological Infrastructure Investment Framework (EIIF) is of significant importance for the region and as a case study globally.

*Nuweberg Dam in catchment G40C. This area is undergoing substantial change as it is cleared of pine plantations, but much of its future is uncertain as forestry gives the land up, but conservation agencies do not have the budget to take on the land and invest in adequate restoration. It is also being developed by the City of Cape Town as a wellfield for bulk water abstraction from the Table Mountain Group Aquifer (Photo: Andrew Turner)*

*Cape Flats: Lower Urban Catchments*

Water and nutrient cycles differ substantially in these lower catchments, which are mostly low-lying coastal floodplains now dominated by engineered infrastructure and hydrologic alterations influenced by socio-economic systems. Underlying a large part of these catchments is the sandy Cape Flats Aquifer (CFA) which has also recently become a key source of bulk water supply for the City of Cape Town (City of Cape Town 2019).

Pre-urbanisation, this landscape was characterised by sand dunes and depressions, perennial streams and seasonal wetlands. Despite its close proximity to the upper catchments, mean annual precipitation is substantially lower at 500 mm/a (Bailey and Pitman, 2016). Geologically, the Cape Flats aquifer is predominantly formed of Quaternary sediments of the Sandveld Group, and is broadly characterised by high recharge rates, low residence times and possibly good hydraulic connectivity with rivers and wetlands (Adelana, Xu and Vrbka 2010). The CFA does exhibit spatial heterogeneity however, where in parts it is semi-confined by calcrete or clay lenses which may limit hydraulic connectivity of rivers and wetlands to the uppermost unconfined sand unit (Adelana, Xu and Vrbka 2010; Hay et al. 2015).




*Transmissivity of the Cape Flats Aquifer, highlighting the best areas for implementing groundwater development schemes (image taken from S. Adelana, Xu, and Vrbka 2010).*

Urbanisation has altered the natural drainage features of these catchments substantially, both above and below ground. Surface drainage features have either been canalised or buried and in many cases are now used as conduits for wastewater effluent. For example, both the Kuils (G22E) and Eerste (G22H) rivers were historically highly seasonal in flow but are now perennial due to treated effluent discharges from Scottsville, Bellville and Zandvliet WWTWs in the Kuils river, and from the Stellebosch and Macassar WWTWs in the Eerste river (Thomas et al. 2010). As these catchments became more urbanised the increase in impervious surfaces, known as catchment hardening, has increased stormwater runoff rates and 'flashiness', and decreased potential recharge capacity. Paradoxically however, leaky pipes carrying drinking water, sewage and stormwater may contribute substantially to groundwater recharge (Kaushal and Belt 2012). Water supply pipes for example are under pressure and have typical leakage rates of ~ 15-30% (Garcia-Fresca 2007), although municipalities have worked hard to reduce these losses during the "Day Zero" drought. Sewer pipes can leak both ways, depending on groundwater level and the level/pressure of water in the pipe, resulting in either groundwater flowing into sewer pipes and augmenting baseflow, or out of sewer pipes to recharge (and pollute) groundwater. This will have important implications for water, carbon and nutrient budgets of riparian/wetland ecosystems and the CFA, which in parts is observed to have relatively high contaminant loading (Adelana and Jovanovic, 2006), and indeed False Bay (Pfaff et al. 2019).

The Cape Flats Aquifer has been highlighted as highly vulnerable to contamination (Musekiwa and Majola 2013), climate change (Villholth et al. 2013), and the combination of these and human dependence on the resource (van Rooyen, Watson, and Miller 2020). These factors are major challenges faced by the City of Cape Town's investment in an extensive CFA wellfield and associated systems to facilitate managed aquifer recharge (MAR), which in itself poses a number of novel challenges and uncertainties (Bugan et al. 2016; Zhang, Xu, and Kanyerere 2020). This dependence on both direct local human activities and global climate change, and the potential impact on human wellbeing and the economy, make the study of the CFA as a social-ecological system a rich, complex, and essential research endeavour.

*Wetlands*

Many seasonal wetlands in these catchments have been filled in for development, but several do remain, albeit highly modified and managed (Lemley et al. 2019; Hutchings, Forsythe, and Clark 2016). As recipients of much of the urban stormwater runoff, these systems are hyper-eutrophic with extensive phytoplankton, reed and water hyacinth growth observed in Zeekoevlei, Rondevlei (both part of the False Bay Nature Reserve Ramsar site) and Princessvlei. Despite plant growth being problematic and requiring frequent manual removal, this considerable biomass does play its role in the uptake of the excess nutrients entering and exiting these systems. For example, long term monitoring of Zeekoevlei by the City of Cape Town has shown a substantial decrease in nitrogen concentration from inflow to outflow (City of Cape Town *unpublished data)*. The role these wetlands play in mitigating contaminant loading into False Bay may be underestimated.

*The view from Table Mountain National Park overlooking Sandvlei with Zeekoevlei and the False Bay Nature Reserve and Ramsar Site beyond. Boland Mountains in the distance. (photo: Jasper Slingsby)*

*False Bay: Coast*

False Bay, located southeast of Cape Town, is South Africa's largest natural bay. Its shores host several million people and it is popular with fishers, swimmers, and recreational beach users. Like many urbanized African bays, False Bay experiences frequent declines in water quality due to anthropogenic pressures such as sewage, agricultural and urban runoff (e.g., pesticides, fertilizers, farm waste, litter; (Binning and Baird 2001; O'Callaghan 1990)), and there is also the possibility of atmospheric deposition of pollutants originating inland (e.g.

Abiodun et al. 2014). Together, these have serious negative impacts on the ecology of the bay, with economic knock-on effects via fisheries, and amenity, recreation and tourism values (Pfaff et al. 2019). Rapid population growth is increasing pollutant loading, with predictions that by 2020, the effluent of 2 million people will enter the bay, mainly through the 11 estuaries that discharge into it.

The Cape Flats have been termed the 'headwaters' of False Bay (Hay et al., 2015) via groundwater and surface water discharge (e.g. Kuils & Eerste, Zeekoevlei, Zandvlei etc). $NO_3^-$ and $PO_4^{3-}$ concentrations of groundwater seepage between Zeekoevlei and the Kuils river were observed to be up to two orders of magnitude higher than offshore waters of False Bay (Pfaff et al. 2019 and references therein). However, the authors highlight that significant nutrients are supplied to surface waters in the bay via wind-driven upwelling of deeper waters. There is a clear need to improve our understanding of the total quantities and relative contributions of anthropogenic vs. natural sources of nutrients and how they are changing over time, given the rapidly growing urban population and changing wind field that drives nutrient upwelling in the bay.

False Bay is a dynamic social-ecological system where a productive coastal ecosystem interfaces with a vibrant socio-economic environment (Pfaff et al. 2019). It is both a key national asset and a natural social-ecological laboratory. False Bay is thus well poised to make a meaningful contribution to regionally unique research opportunities in support of addressing several grand challenges, including understanding a changing planet, adapting the way we live, reducing the human footprint and sustainably unlocking South Africa's blue economy ("The Global Change Grand Challenge National Research Plan" 2009).

It is against this backdrop that the Shallow Marine and Coastal Research Infrastructure (SMCRI) will be developing the Two-Oceans Sentinel Site. It is envisaged that the site will be located between Betty's Bay and Cape Town, incorporating False Bay and several Marine Protected Areas managed by SANParks and CapeNature, aimed at sampling the cold-temperate overlap region between the Agulhas Bioregion and the South-western Cape Bioregion. The Site will be characterised by a series of in situ coastal sensor moorings to measure currents, waves and temperature throughout the water column from inshore (shallow subtidal) to offshore (~ 100 m depth). Long-term observations of coastal features such as sandy beaches, surf zones, estuaries, subtidal reefs, islands and rocky shores will also be instituted (or supported where they already exist) and will consist of in situ sensors, transect/quadrat surveys, remote sensing surveys, etc. A pelagic ecosystem LTER programme will be developed for False Bay that will collect monthly data of key essential ocean (EOV) and biodiversity variables (EBV) focussed on biogeochemical and plankton dynamics. The exact location of the instrumented sites will be selected through a consultative process, but it makes sense that the observatories are located in such a way to capture all the major drivers of coastal variability, including catchment input such as water quality and quantity which is where this proposal provides for such linkages to be formed.

Establishing a coordinated set of physical, chemical and biological long-term observations from the catchment to the coast related to weather, eco-hydrology and energy-carbon-water flux will not only enhance the value of the SMCRI and EFTEON sites, but also offer cost efficiencies in terms of platform sharing and maintenance. SMCRI commits to support the proposed landscape by making available its research infrastructure (estuarine vessels, sensors, biogeochemistry laboratory facilities, offshore automatic coastal weather stations and Airborne Remote Sensing Platform), human resources (skippers, divers, technicians) and available datasets.

*The (Urban) Watershed Continuum: Tracking watershed nutrient loading*

Streams, rivers and riparian/wetland ecosystems are receivers, transporters, transformers and storage sites of organic matter, carbon, nitrogen and other biogeochemical constituents.  Urbanisation has altered the patterns, pathways and processes by which watersheds store and transport runoff, groundwater, baseflow and transform carbon and nitrogen.  The urban watershed continuum (Kaushal and Belt 2012) is a framework that comes out of the Baltimore Ecosystem Study LTER and considers the continuum between engineered and natural hydrologic flowpaths. It proposes hypotheses with which to explore the nature of the hydrologic connectivity and how it influences the fluxes and transformations of carbon, contaminants and nutrients over space and time. Combining this framework with regular sampling throughout the catchment of N and oxygen (O) isotopic composition ($\delta^{15}N$ and $\delta^{18}O$) of nitrate and the $\delta^{15}N$ of ammonium will allow us to identify and track anthropogenic versus natural nutrient inputs, and understand their sources, cycling and fate (e.g.,  Nestler et al., (2011).  These efforts will be in conjunction with and complement ongoing research within BIOGRIP (run out of PI Fawcett's Marine Biogeochemistry Lab and funded by the Royal Society/African Academy of Sciences) that is focused on investigating drivers and indicators of water quality in False Bay, with the ultimate goal of developing mechanisms for communicating predicted declines in water quality to relevant stakeholders.

### Societal context and opportunity to observe social-ecological systems

This landscape nomination is strategically positioned as part of the Cape Metro Region (CMR), recognising that "all humanly used resources are embedded in complex, social-ecological systems" (Ostrom 2009). The City of Cape Town recently experienced a multi-year drought, which brought the relationship between the city and its natural environment into stark focus (Otto et al. 2018; Sousa et al. 2018; Kaiser and Macleod 2018). This makes for fertile ground for social-ecological systems (SES) research, as few people in the region can deny the need to understand our changing environment, from environmental provisioning to societal needs, to inform management for a sustainable future (Enqvist and Ziervogel 2019). Further, the need to explicitly include human drivers such as decision-making processes, cultural institutions, urban planning, and economic systems in our analyses of ecosystem dynamics is increasingly clear (Redman, Grove, and Kuby 2004; Grimm et al. 2000). Examining patterns in land use and cover, production, consumption and disposal will provide an appropriate framework (*sensu* Redman et al., 2004) to explore the interactions between the various SES and the interactions between the social and the ecological components (see **Figure 2**). This framework arose from dedicated efforts of multiple social and natural systems scientists of the LTER Network in the United States to integrate social science into LTER. This proposed landscape provides an opportunity to build on this framework in a global South context, and test its relevance to the challenges most representative of the region and South Africa in particular. This approach will also require concerted efforts from all stakeholders of this landscape which, while difficult to achieve, has many additional benefits through co-learning.

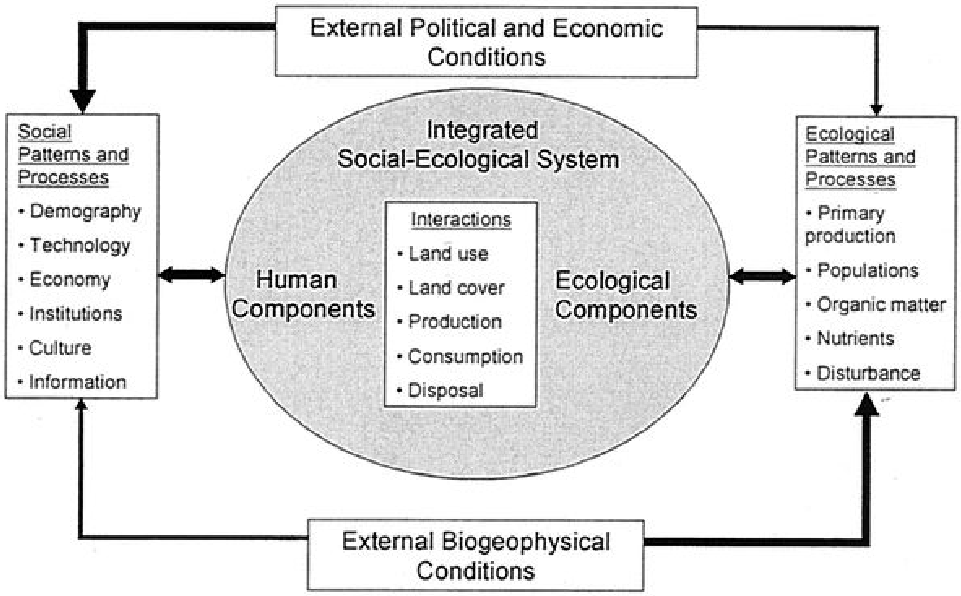



***Figure 2.*** *Conceptual framework proposed by (Redman, Grove, and Kuby 2004) on how to integrate social science into LTER.*

As was highlighted in the previous section, this landscape contains multiple, nested and interacting SESs relating to water. The need to understand patterns in production, consumption and disposal in relation to ecological, hydrological and climatic dynamics is becoming increasingly recognised, particularly for water (e.g. CoCT, 2019). **Figure 3** illustrates the urban water cycle of the City of Cape Town (Atkins et al., *in revision*) which quantifies the various human-mediated and hydrologic flows of water into, out of and within the City of Cape Town. While it is a broad overview of the system's water fluxes, it serves as a heuristic model that is relevant to planning and implementation processes as well as useful for identifying mechanisms and interactions driving this water cycle. The data provided by this proposed research platform would allow us to broaden the perspective further and examine water dynamics and inter-relations at the regional scale. This would reveal the interdependence of neighbouring municipalities on common water resources and reliance on external sources, as has been highlighted in the Greater Cape Metro Regional Spatial Implementation Framework (Department of Environmental Affairs and Development Planning 2019) and the City of Cape Town's Water Strategy (City of Cape Town 2019).

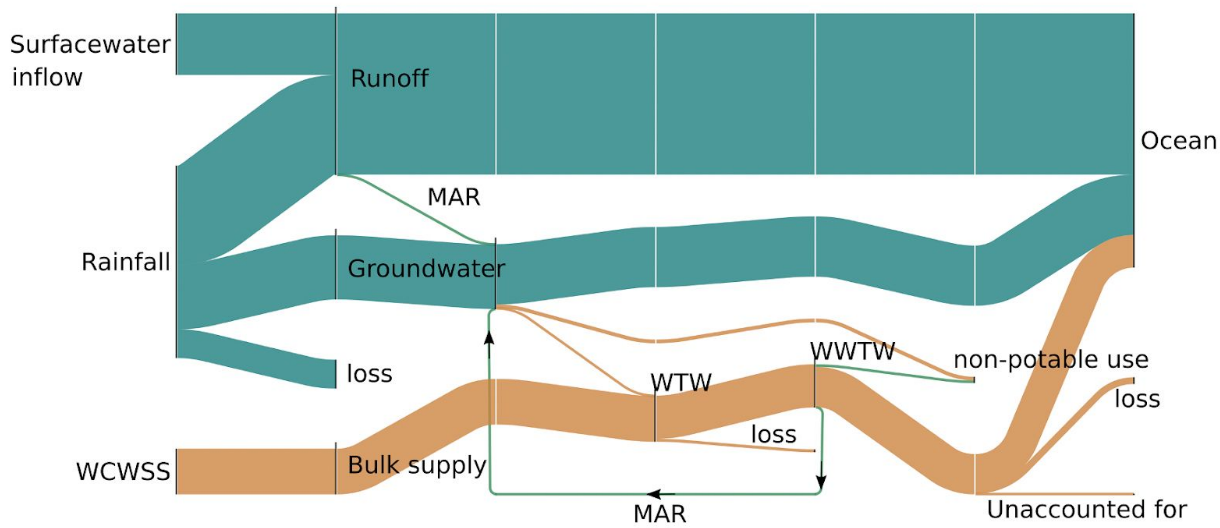
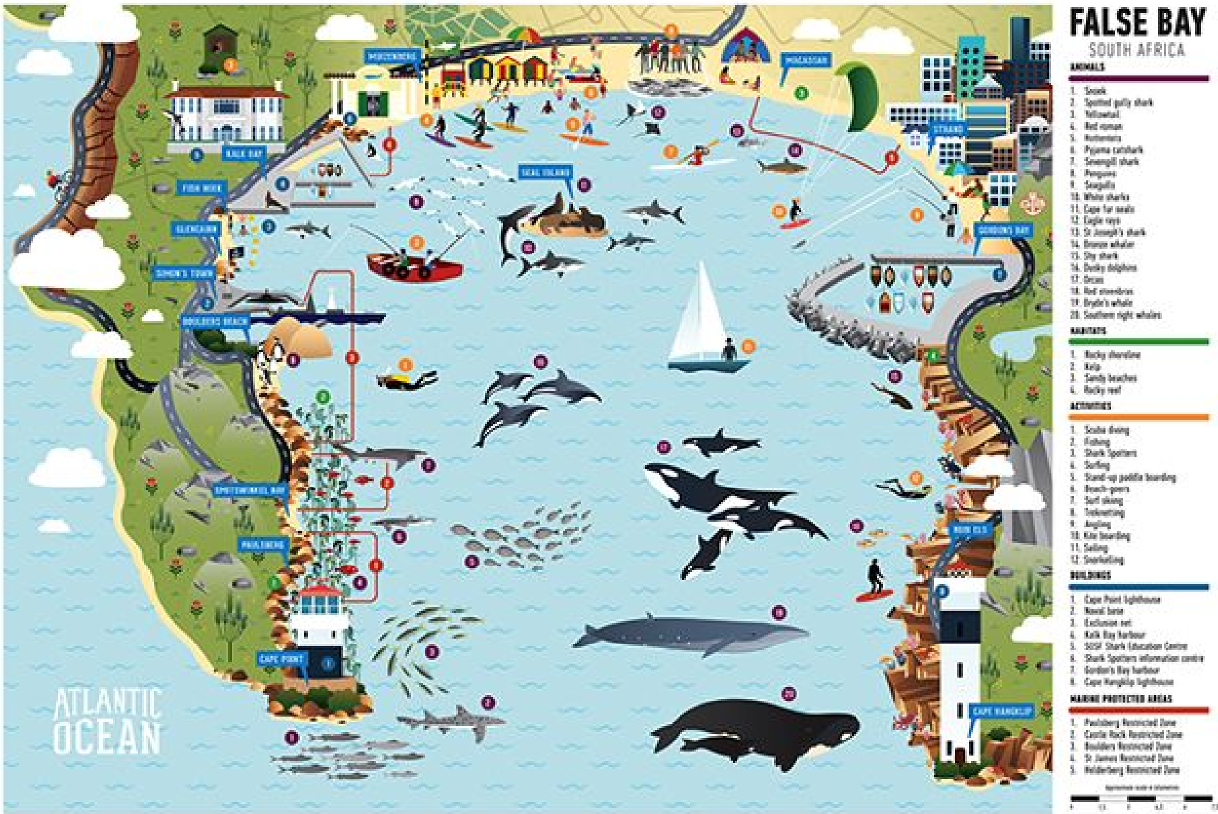



***Figure 3.*** *Urban Water Metabolism of Cape Town representing hydrological (teal) and anthropogenic (orange) flows into the urban system and out into the coastal ocean. Thickness of line is proportional to flow rate (Mm$^3$ per annum). With some modification, this sankey diagram can serve as a heuristic representation of the hinterland/urban/coastal connectivity (Atkins et al., n.d. in revision)*

Beyond water, there are a multitude of other opportunities for SES research, as evidenced by the growing SES literature from the Greater Cape Town region. Crane and Swilling (2008) provide an overarching review of the status quo for the Greater Cape Town region's resource use in terms of water, energy, waste, land, biodiversity, food and transport. They go on to highlight a number of options for transitioning to more sustainable resource use, arguing that attempts to grow the economy and alleviate poverty will fail unless they are designed and implemented in a manner that recognises environmental resources and ecosystem services as binding constraints. Encouragingly, and despite an intervening decade of troubled politics, some progress has been made on most of their suggestions. While many are in their infancy, this is the perfect time for research to track their progress, help inform decision making and implementation, and communicate more widely the successes or failures and their respective drivers.

Some key and current issues within the proposed landscape include topics like land invasions and the implications they have for local and distant communities. For example, recent land invasions of municipal nature reserves along the coastal foredunes in False Bay come at a direct cost to biodiversity (habitat loss), but also come at a cost to the ecosystem service of coastal protection, making the new community and their neighbours vulnerable to storm surges and sea level rise. A similar case is seen where the informal settlement of Siyanyanzela, Grabouw, is expanding into the upper Steenbras catchment. This accentuates the local community's vulnerability to fire, while also threatening the regional community's water supply (i.e. City of Cape Town).

The site would serve to curate urban ecological research undertaken in the Cape Metro to date (see for example (P. Anderson et al. 2020; Brom et al. 2020; Suri et al. 2017; Brill, Anderson, and O'Farrell 2017a, [b] 2017; P. M. L. Anderson, Avlonitis, and Ernstson 2014), and allow for a framing of work moving ahead in a manner that will allow for cross-city comparisons. Urban ecological research in the site is well catered for with matched ecological and social gradients notably in G22B, D, E and H. Here critical biodiversity and highly varied human settlement make this a fascinating site in which to study the human-nature interface, both with respect to meeting conservation agendas, but also in the context of environmental justice, liveable cities and ecosystem services (O'Farrell et al. 2012). The opportunity for a large collective research endeavour would favour urban ecology research with the multiple inputs of ecological, biophysical and social data towards understanding the complexities of ecological outcomes in response to social pressures. This opportunity would put South Africa in a unique position to engage in comparative urban ecological research, contributing to contemporary debates such as the urban homogenisation debate, and the role of the luxury effect (Nerlekar et al. 2019; Chamberlain et al. 2019) from an African perspective, driving theory formation from the continent. This landscape is also novel in that it affords the opportunity to explore SES that transcend terrestrial, freshwater and coastal/marine boundaries. Pfaff et al. (2019) outline a vast range of SES research in the marine and coastal environment (see **Map 5** for an illustrative summary), many of which have strong terrestrial links via the flows of people, freshwater, aerosols, nutrients or pollutants that offer opportunities for transformative research.




***Map 5.*** *Idealized map highlighting various components of the socio-ecological system of False Bay. (Source and credit: artist A. de Korte under commission of the Save Our Seas Foundation for their Magazine). " (taken from Pfaff et al. 2019)* [*https://doi.org/10.1525/elementa.367.f14*](https://doi.org/10.1525/elementa.367.f14)

The opportunities to observe SESs at various scales in this landscape and surrounds are vast and do not all need to be identified definitively *a priori.* However, there are several framing documents that have identified development challenges and goals for the region, several of which we aim to align with from the outset. These include the Greater Cape Metro Regional Spatial Implementation Framework (2019), City of Cape Town Water Strategy (2019), CoCT Municipal Spatial Development Framework CoCT-MSDF (2018), the Ecological Infrastructure Investment Framework (DEA&DP in prep) and many others. Aligning the focus of this landscape with governance and planning issues - particularly in relation to water, biodiversity, restoration, fisheries, etc will greatly enhance its impact.

## Academic setting

The Greater Cape Town region is considered the intellectual hub of sub-Saharan Africa, with Education & Academic Research highlighted as a regional comparative advantage of global significance in the GCM regional spatial implementation framework (Department of Environmental Affairs and Development Planning 2019). Our broader landscape includes four tertiary institutions (Cape Peninsula University of Technology (CPUT), Stellenbosch University (SU), the University of Cape Town (UCT) and the University of the Western Cape (UWC) - all of whom are represented on the proposal team), two offices of the Council for Scientific and Industrial Research (CSIR; Stellenbosch and Cape Town), the South African National Biodiversity Institute (SANBI) and numerous smaller higher education institutions and research groups. The stature of these institutions is such that they attract significant international interest and collaboration, and they host a large number of DST-NRF Centres of Excellence, SARChI Research Chairs and other units or research groups of significant relevance to EFTEON and our proposed landscape. These include, inter alia:

- DST-NRF Centre of Excellence in Scientometrics and Science, Technology and Innovation (STI) Policy (SciSTIP) - part of the Centre for Research on Evaluation, Science and Technology (CREST) - SU
- DST-NRF Centre of Excellence for Invasion Biology (CIB) - SU
- DST-NRF Centre of Excellence Birds as Keys to Biodiversity Conservation - UCT
    - Linked to the FitzPatrick Institute of African Ornithology
- DST-NRF Centre of Excellence in Food Security (FS) - UWC
- African Climate and Development Initiative (ACDI) - UCT
- Centre for Complex Systems in Transition (CST) - SU
- Climate Systems Analysis Group (CSAG) - UCT
- Future Water Institute - UCT
- Institute for Water Studies - UWC
- Stellenbosch University Water Institute - SU
- Statistics in Ecology, Environment and Conservation (SEEC) - UCT
- Plant Conservation Unit (PCU) - UCT
- The Applied Centre for Climate & Earth System Science (ACCESS) - CSIR
- African Centre for Cities - UCT

- South African National Biodiversity Institute
- The Marine Biogeochemistry Lab - UCT
- Centre for Water & Sanitation Research - CPUT
- Centre for Sustainable Oceans - CPUT
- Africa Space Innovation Centre - CPUT
- French South African Institute of Technology (F'SATI) - CPUT
- Freshwater Research Centre
- SANParks Scientific Services
- CapeNature Scientific Services

Water will be a key theme for this landscape, which would be well supported by the local academic community. All four local higher education institutions have centres or institutes focused on water research, including the Centre for Water & Sanitation Research (CPUT), the Future Water Institute (UCT), the Stellenbosch University Water Institute and the Institute for Water Studies (UWC). Each of these have slightly different foci and specializations from engineering and urban design to hydrology, biogeochemistry, pharmaceutical pollutants and social-ecological systems. This proposed EFTEON landscape provides a great opportunity to bring their respective expertise together around a few focal catchments.

This landscape also offers key opportunities to dovetail with and leverage the strengths of other SARIR projects. Collocating this landscape to interface with the SMCRI Two Oceans Sentinel Site allows us to sample a continuum from the mountain peaks into the marine environment, while partnering with multiple nodes of the Biogeochemistry Research Infrastructure Platform (BIOGRIP) provides us with significant capacity to do detailed analytical processing of samples collected by the EFTEON and SMCRI teams. For example, under the auspices of BIOGRIP, the Marine Biogeochemistry Lab at UCT (UCT-MBL; co-PIs Dr S Fawcett and Dr K Altieri, part of the BIOGRIP Isotope Biogeochemistry Node) is working on a project investigating drivers and indicators of water quality in False Bay, with the ultimate goal of developing mechanisms for communicating predicted declines in water quality to relevant stakeholders. The UCT-MBL recently installed the denitrifier-IRMS method (Sigman et al. 2001; Casciotti et al. 2002; Weigand et al. 2016) which allows for high-sensitivity analysis of the isotopic composition of virtually all nitrogen species. UCT-MBL is the only laboratory on the African continent that can make the inorganic N isotope measurements that are needed for the denitrifier-IRMS method which is the global standard for all studies of N inputs to, removal from, and cycling within waterways, fresh- and salt.  In addition, the Global Atmospheric Watch tower at Cape Point (within the BIOGRIP Atmospheric Biogeochemistry Node) measures aerosol nitrate and ammonium isotopes (e.g.,  (K. E. Altieri et al. 2013; Gobel et al. 2013). Combined with air mass back trajectories computed using NOAA's Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model and $^{222}$Rn concentration data provided by the South African Weather Service (itself part of BIOGRIP), it will be possible to constrain where the air masses (and their associated pollutants) are coming from. Lastly, we understand that the South African Population Research Infrastructure Network (SAPRIN) intends to begin developing their Cape Town Surveillance through Healthcare Action Research Project (C-SHARP) node at Nomzamo and Bishop Lavis in 2021, providing the opportunity to link to a fourth SARIR project.

Note that we have not focused on international stakeholders as it would rapidly become overwhelming. Instead we have focused on the local research community, many of whom are of significant international stature and would bring their international collaborators onboard. That said, we have engaged with a few key international groups whose experience and/or collaboration would be of great value to developing this landscape should it be selected.

The Central Arizona Phoenix (CAP) -LTER, which started in 1997 was one of the first urban LTERs, along with Baltimore Ecological Study (BES), and has contributed substantially to the field of urban ecology, among others. They engage biological, physical, engineering and social-scientists in research that provides a foundation for understanding urban socio-ecological systems in an arid and growing metropolitan area. Their experience and insight establishing an LTER through a transdisciplinary lense will be invaluable to the initial years of this endeavour. Our proposed research landscape holds the potential to support research that may contribute a global south/African perspective to the rapidly emerging field of urban science. Associated with CAP-LTER, and equally supportive, is the Urban Resilience to Extremes Sustainability Research Network (UREx-SRN) which focuses on integrating social, ecological and technical systems to support decision making regarding urban infrastructure and climatic uncertainty. The Nature-based Solutions for Urban Resilience in the Anthropocene (NATURA) network is another international network that has given their support and indicated their interest in this research platform. This network is global in scope and is a  transdisciplinary 'network of networks' of researchers and practitioners working in nature-based-solutions (NBS) and urban sustainability science.

Lastly, the proposed landscape extent has already been chosen to be the core focus for the first ever biodiversity-focused NASA airborne field campaign. The NASA Biodiversity and Ecological Forecasting program is supporting the Biodiversity Survey of the Cape (BioSCape), which will run from 2021-2024. The campaign is organized around three major themes: 1) the distribution and abundance of biodiversity, 2) the role of biodiversity in ecosystem function, and 3) the impacts of biodiversity change on ecosystem services. It will be accompanied by a focused National Science Foundation (NSF) funding call to encourage US researchers to participate in the programme and we are looking to convince the South African National Space Agency (SANSA) and others to have similar focused calls for South African researchers. The NASA BioSCape campaign has great potential to boost the international profile of the GCT-LTSER and EFTEON in general early in the establishment of the landscape.

## The landscape location in the face of global change

### Climate: patterns, trends and projections

Reduced precipitation has been observed in many Mediterranean-Type climates of the southern hemisphere (Garreaud et al. 2017; Smith et al. 2000), with observed and modelled long-term increases in aridity for most of southern Africa (Otto et al. 2018; Lehner et al. 2017; Feng and Fu 2013). Historical rainfall trends in the winter rainfall region are, however, strongly spatially heterogeneous and manifest differently at different temporal scales (Wolski et al. 2020- see Figures 4-6 below). Long-term rainfall trends indicate general drying, but are strongly influenced by the severe 2015-2017 drought, and trends prior to the drought are very spatially diverse.  In particular, the proposed landscape spans the lowland region characterized by a relatively consistent drying, while the region to the east of the Boland Mountains (Overberg) manifests long-term and recent wetting, with the Boland

Mountains forming the transition between the two. Understanding of rainfall variability in these and other mountains in the region is difficult, mostly due to the fact that there are very few long-term stations in the Western Cape that are located above 500 m a.m.s.l. (Wolski et al. 2020). There are indications that rainfall trends are different between the mountains and the lowlands (e.g. Burls et al. 2019), although Wolski et al. (2020) identify only the difference in 2015-2017 drought signal, but no difference in the trend signal between these regions. A key focus of this proposed landscape would be improved understanding of weather patterns (and ultimately trends) in the Boland Mountains Strategic Water Source Area.

In spite of diversity of rainfall trends, a DWS time-series from 1956-2017 of streamflow in the Upper Berg Catchment (just North of the proposed area) revealed a significant drying trend and a longer summer low flow season (Jury 2020). This might be a result of superposition of rainfall and temperature and thus evaporation trends, but Jury's analysis does not account for the known impact of alien tree invasions on streamflow, which are significant for the catchment in question (Le Maitre et al. 2019). Regionally, there is strong evidence for warming of the climate system (Jury 2020; Sousa et al. 2018), although other factors such as wind and humidity might complicate the temperature-evaporation relationship (Hoffman et al. 2011).

Anthropogenic influence on the climate of the study region manifests through changes in hemispherical scale processes and regional scale dynamics affecting the mid-latitude westerly circulation that is the main source of the region's rainfall. Global climate models robustly simulate poleward expansion of the tropics (Hadley cell, or tropical high pressure systems), poleward displacement of mid-latitude storm tracks, increase in strength and a poleward shift of the westerly winds and subtropical jet-streams, and a shift toward a more positive phase of the SAM/AAO, both in historical and future simulations. These effects are physically consistent with the understanding of climate system behaviour under greenhouse gas forcing. Also, they have been associated with the recent drying trends and shown to underlay the 2015-2017 drought (Otto et al. 2018; Sousa et al. 2018; Burls et al. 2019; Mahlalela, Blamey, and Reason 2019).  There is, however, little consistency between the hemispheric processes and rainfall responses in the long-term, with previous 20th century droughts (in the 1930s and 1970s) not clearly reflecting GHG-related trends (see the **Figures 4-6** below), and with an overall weak or increasing rainfall in some parts of the winter rainfall region at the time scale of 90 or more years (Kruger and Nxumalo 2017; Wolski et al. 2020). In spite of this inconsistency, the overall consensus is that of a drier future, with either a warmer and drier climate or a much warmer and considerably drier climate (Otto et al. 2018, Sousa et al., 2018).

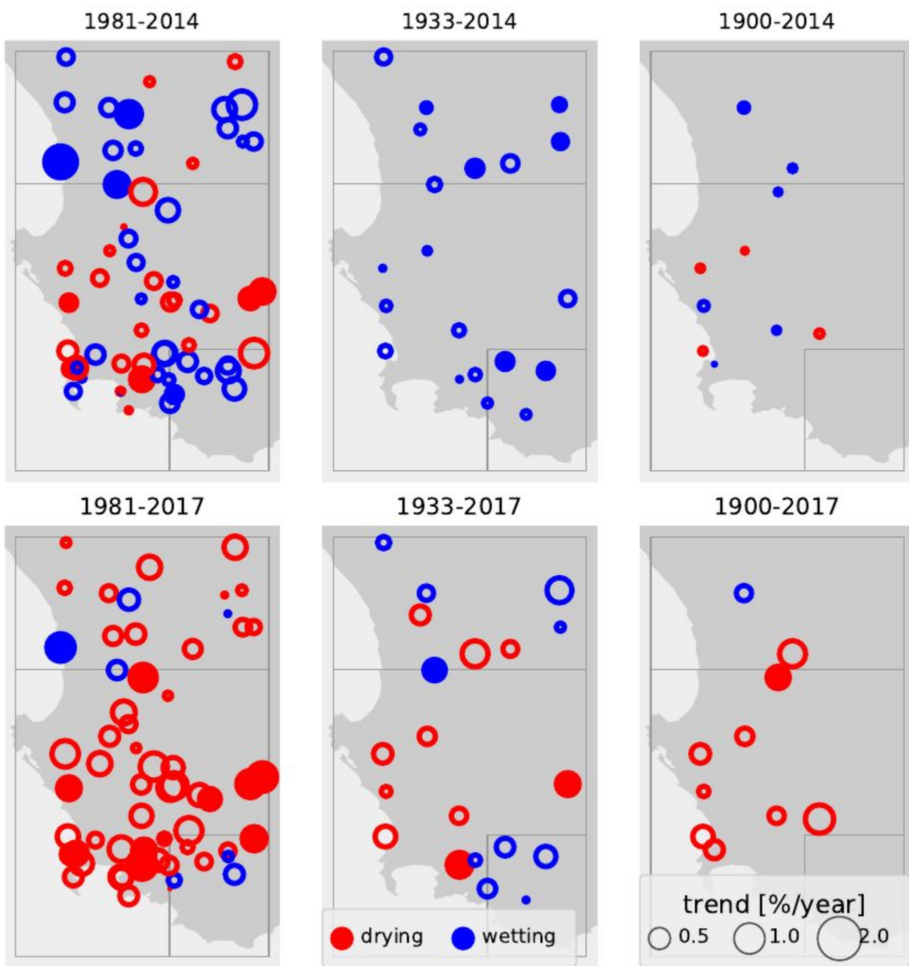



***Figure 4.*** *Trends in total annual rainfall at individual rainfall stations at three time scales, spanning the period up to the 2015-2017 drought (upper row), and including the drought (lower row) (from Wolski et al. 2020).*

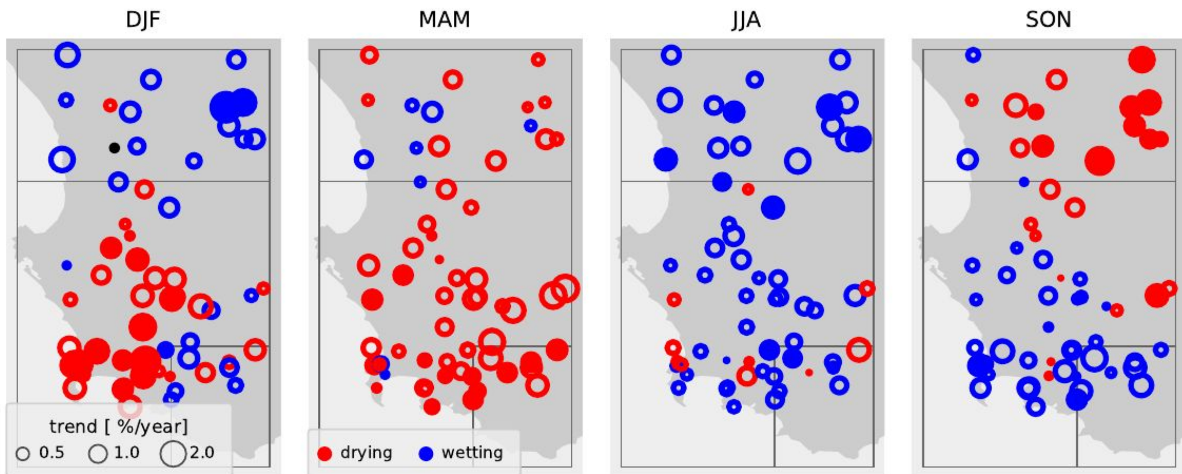



***Figure 5.*** *Trends in total seasonal rainfall at individual rainfall stations in 1981-2014 (i.e. not including the 2015-2017 drought). (From Wolski et al. 2020)*

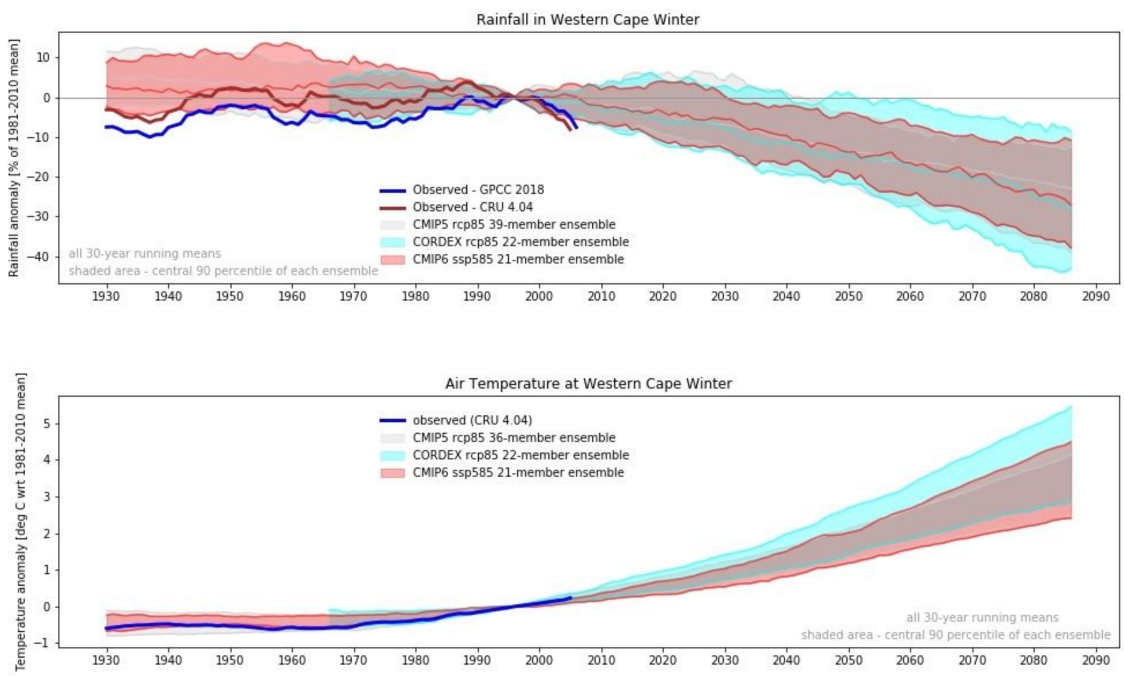



***Figure 6.*** *The range of projected future changes in total annual rainfall and mean annual temperature over the Winter Rainfall region of South Africa from three contemporary datasets - state-of-the-art generation of global climate models from CMIP6, previous generation of GCMs*

*(CMIP5) and mid-resolution dynamically downscaled projections (CORDEX) for high ("business-as-usual") greenhouse gases emission scenarios. Also included are historical observations from different datasets (provided by Climate System Analysis Group).*

The social and economic impacts of the recent drought were severe. 2017/2018 major crop production was 20.4% lower from 2016/2017, representing a R5.9 billion loss in industry and an associated 30,000 jobs of seasonal farm workers, and expected reduced harvests to last 8-10 years (Pienaar and Boonzaaier 2018). Data suggest a decrease in visitors to the region between 2017 and 2018, with expected repercussions for related businesses. Other businesses were also hard hit, e.g. garden centres, construction and building, swimming pool producers, while others were thriving, e.g. water tank distributors, borehole installations and bottled water (Parks et al. 2019). In addition, owing to municipal water demand interventions, the city faced a dramatic reduction in their revenue due to reduced water sales, leading to a shortfall of close to R2 billion ($14 million). The CoCT water budget and provision of services through the water department had to be subsidised at the expense of other programmes, reducing their yearly budget and expendable assets (City of Cape Town 2018a)

While direct impacts of the drought on ecosystems and their biodiversity are still being quantified, impacts observed in fynbos vegetation within the Greater Cape Town region include high mortality of plants in mature stands (i.e. 15+ years since fire), while recently burnt stands showed slower than expected post-fire regrowth (Slingsby, Moncrieff, and Wilson 2020). While no reports of impacts on plant species diversity and/or functional composition have yet been published, a previous analysis of a 44 year repeat vegetation survey (1966-2010) found a significant decline in species numbers that was particularly severe in sites that had suffered extreme hot and dry periods in the first year after fire (Slingsby et al. 2017). Preliminary analyses of a 2018 survey of the same releves suggest there has been significant further decline in species numbers at these sites (Slingsby et al. *in prep*). Other anticipated impacts include reduced flower/cone and seed production, which may have knock-on impacts depending on whether these populations get sufficient time and favourable conditions to build up their seed banks before the next fire (Treurnicht et al. *in prep*). For aquatic animals drought can directly affect ponds by drying them up which significantly affects aquatic beetle species richness (Jooste, Samways, and Deacon 2020), although this may be mitigated to some extent and for certain species by artificial water bodies  (Samways et al. 2020). For fish, the drying up of river stretches can directly affect populations and interfere with breeding movements (Cerrilla 2020) and is likely to impede movements of amphibians and negatively affect obligate wetland dwelling frogs.

Our proposed landscape offers substantial opportunities to study both climate systems and the impacts of climate change. It captures steep elevation gradients from sea level to over 1500m and has strong oceanic influence, with an associated rainfall gradient from ~500 to ~3350mm. Multiple peaks are accessible by road (two within the core landscape and multiple others within the broader landscape), making it relatively easy to explore this gradient. The landscape contains perhaps the most dense network of government run weather stations in the country, including many with records extending over 100 years, and there are many times more stations run by companies or private individuals (farmers, hobbyists, etc).  Somewhat surprisingly, the weather network is relatively sparse at high elevations. Given the importance of the mountain catchments for the region's water supply, it would likely be a priority for this EFTEON landscape to address this gap by establishing weather observations along the accessible elevational transects.

Beyond direct climate impacts on biodiversity there are also more complex impacts that precipitate through feed backs in various social-ecological systems. For example, efforts to mitigate the impacts of extreme events and/or climate change can have direct negative impacts on the environment, such as the expansion of bulk water infrastructure in hyperdiverse and listed threatened and/or protected ecosystems (Nordling 2018).

## Air quality and atmospheric deposition

Air quality in the Greater Cape Town region varies by location and weather conditions (City of Cape Town 2016). Low-level temperature inversions with low wind conditions often result in a visible brown haze over the city, particularly in the winter months, but increasingly in summer too. This has several negative impacts, from directly affecting human health (Keen and Altieri 2016) with substantial cost to the economy (Altieri and Keen 2019); deposition in marine, freshwater and terrestrial ecosystems; and further economic impacts on tourism by impairing visibility in a region internationally renowned for its vistas of mountains and seas (Abiodun et al. 2014). While local pollution emanates from transport emissions, industrial processes, waste disposal, wild and domestic fires, Abiodun et al. (2014) have shown that the region is also significantly affected by the transport of atmospheric pollutants from the Mpumalanga Highveld.

The City of Cape Town maintains a network of 14 ambient air quality monitoring stations within the Metropolitan area (City of Cape Town 2016). Air is continuously sampled for sulphur dioxide ($SO_2$), oxides of nitrogen ($NO_x$), ozone ($O_3$), carbon monoxide (CO), hydrogen sulphide ($H_2S$) and particulate matter 10 and 2,5 microns in size (PM10, 2.5) every 10 seconds using US EPA approved methods.

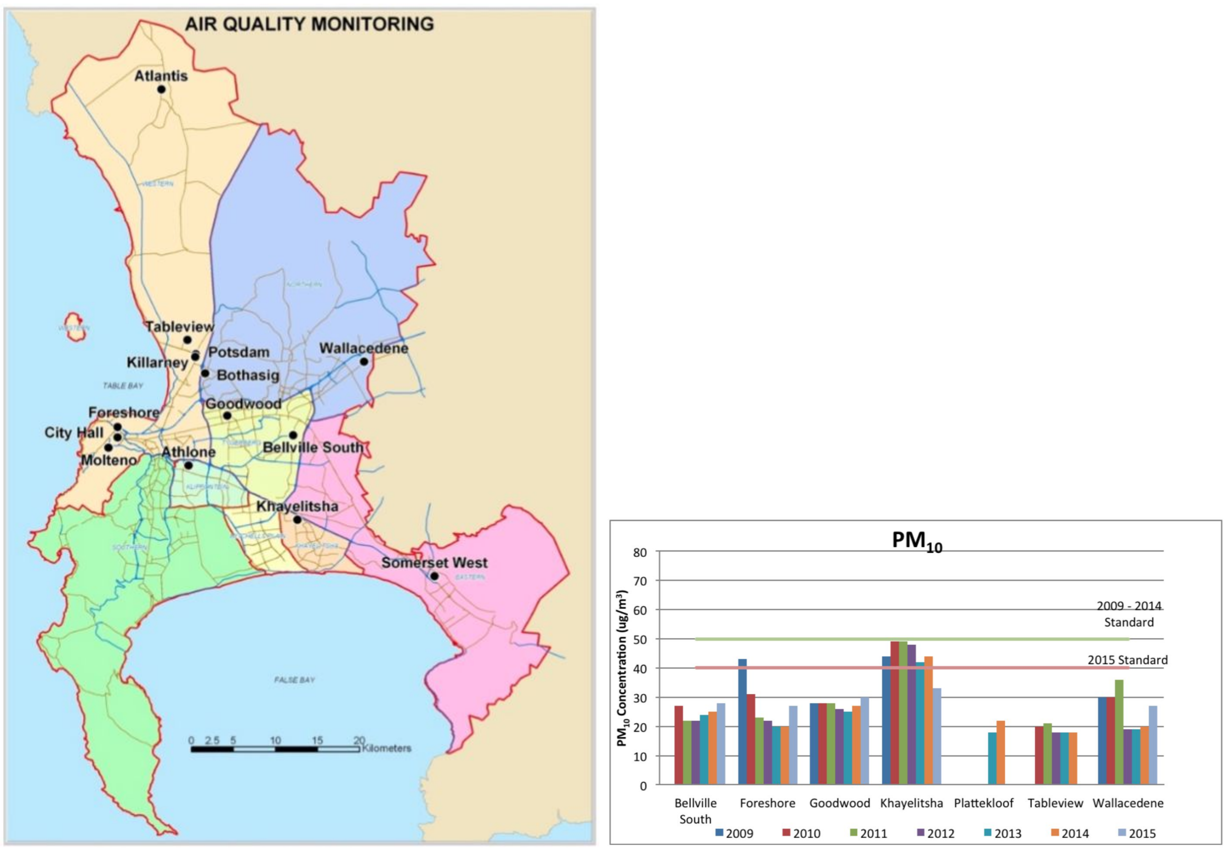



***Figure 7.*** *The City of Cape Town air quality monitoring network and long term trends in $PM_{10}$ (images copied from City of Cape Town 2016).*

This network reveals significant spatial variation in air quality within the Greater Cape Town region. At finer scales, local source emissions result in distinct spatial air quality differences associated with income disparity (Keen and Altieri 2016; City of Cape Town 2016), a big issue in terms of environmental justice.

In addition to the City's monitoring network, the Greater Cape Town region hosts a long term atmospheric observatory in the form of the Global Atmospheric Watch (GAW) station at Cape Point, run by the South African Weather Service. Ambient greenhouse gases have been monitored here since the late 1970s, including the longest-running atmospheric carbon monoxide (CO) dataset in the Southern Hemisphere (Labuschagne et al. 2018). The data are contributed to local and international databases and data centres, including the South African Air Quality Information System (SAAQIS) and the World Data Centre for Greenhouse Gases, where the data are freely accessible. The GAW station is part of the atmospheric node of the BIOGRIP SARIR project.

There is growing evidence that urban ecosystems are becoming hotspots of N deposition (Decina, Hutyra, and Templer 2020 and references therein). Elevated N deposition is a complex stressor as it can have a variety of positive and negative effects, but is observed to be associated with declining species richness (Simkin et al. 2016), increased soil acidification (Lu et al. 2014), eutrophication of waterways (Chen et al. 2018; Bergstrom and Jansson 2006) and adverse impacts on human health (Keen and Altieri 2016). A modelling study of N deposition rates in biodiversity hotspots around the globe by Phoenix et al. (2006) has predicted a nearly two-fold increase in global N deposition rates from mid 1990 to 2050. For the Cape Floristic Region, their model estimates increase from 4 kg N $ha^{-1}$ $yr^{-1}$ to 10 kg N $ha^{-1}$ $yr^{-1}$ in 2050. Using foliar N content in bryophytes in Cape Metropolitan Areas, Wilson et al. (2009) observed an increase in foliar N coinciding with rapid urbanisation and estimated an increase in N deposition rates by about 6-13 kg N $ha^{-1}$ $yr^{-1}$ over the last 60 years with greatest increases estimated on the Cape Flats. The impact of this increased deposition on fynbos ecology is hypothesised to lead to a significant loss in biodiversity (Wilson, Stock and Hedderson 2009), but remains an under researched area. As fynbos grows in nutrient-depleted conditions, many fynbos plant species have a variety of nutrient uptake traits, which offers one explanation for high species diversity, whereby coexistence is facilitated through avoided competition for soil nutrients (Anderson et al., 2014). Changes in soil chemistry will likely shift the balance in favour of one or a few uptake strategies, resulting in the competitive exclusion of others.

The Cape Town Brown Haze studies (Wicking-Baird et al.,(1997) were instrumental in identifying the main sources of NOx, $SO_2$, $O_3$ and volatile organic compounds in Cape Town. The main anthropogenic activities that contribute to NOx emissions are motor vehicles, industrial emissions (refineries, steel mills, smelters, cement manufacturing, brickworks etc), the burning of industrial waste and domestic activities in residential areas (cooking/heating). Linking these sources of atmospheric N deposition with the N sources in run-off and wastewater (*discussed in Urban Densification: Inward growth)* is necessary for understanding the full extent of the biogeochemical impacts of human activities on coastal systems. However, current assessments of the role of anthropogenic N deposition rely on poorly tested assumptions regarding the origins of the N deposition measured in the atmosphere, primarily due to a paucity of data. Quantifying atmospheric contributions to regional N budgets will provide necessary information for improved management of atmospheric inputs and outputs from local ecosystems. The proposed collaboration with SMCRI and BIOGRIP will allow these dynamics to be explored as part of the social-ecological systems this landscape presents.

## Land use and land cover

The range of land cover and land use types in the landscape have been described in detail in the section on the general situational characteristics of the landscape (see **Figure 1** and **Map 3**) and throughout the proposal where relevant, including the following section on anticipated development pathways. It includes representative near-natural land cover (Forest Biome and a number of Fynbos Biome vegetation formations and types associated with a broad range of different soils and climate (see **Map 4**)) and most modified land cover and use types. There is much interesting variation within the broader land-use/land cover classes too. For example, the cultivated agriculture can be split into irrigated (typically orchards and vineyards) or non-irrigated (grains) fields (Van Niekerk, A., Jarmain, C., Goudriaan, R., Muller, S.J., Ferreira, F., Münch, Z., Pauw, T., Stephenson, G., Gibson, L. 2018), and the crop types vary by climate and/or soil.

*The lower Sonderend catchment (H60A) is dominated by orchards before it drains into Theewaterskloof Dam (Photo: Andrew Turner).*

## Anticipated development pathways for the landscape

"*No other province or city in South Africa has more policies on environmental conservation and sustainable resource use than the Western Cape Provincial Government (PGWC) and the City of Cape Town (CCT).*" - Crane and Swilling (2008).

Similarly, there are many policies and frameworks that are not environmentally focused, but may greatly affect future trajectories of the landscape. The Greater Cape Metro Regional Spatial Implementation Framework (Department of Environmental Affairs and Development Planning 2019) is very valuable in this regard, in that it was co-created as a collaboration among many public and private organizations to better integrate and coordinate the actions stemming from policies set by different wings of government (**Figure 8**). The overarching aim is to balance the competing demands of different stakeholders and communities, with the explicit goals of better social and environmental outcomes. This document will serve as a very useful guide to help scope the potential factors affecting phenomena linked to the different EFTEON themes and specific research projects, and help identify key local partners and stakeholders to include when co-designing the research. The Western Cape Department of Environmental Affairs and Development Planning are very enthusiastic about the prospect of the GCT-LTSER and the potential to work together to help ensure that the "*vision put forward through these frameworks and policies is resilient, balances the current and future demands of the applicable complex social-ecological systems, and is responsive to unforeseen emergent phenomena, especially given the importance of scarce freshwater resources in such a vision.*" - letter of support from Piet van Zyl, Head of Department, Environmental Affairs and Development Planning.

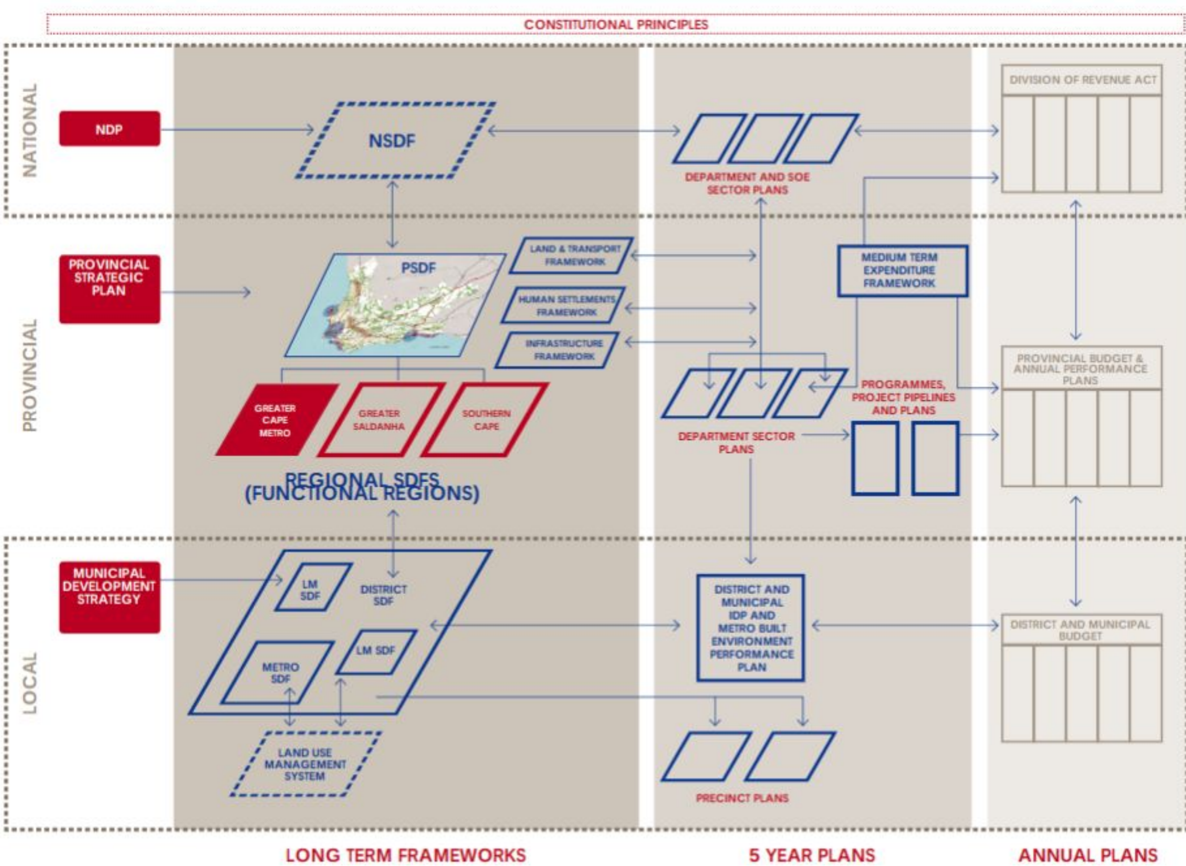



***Figure 8.*** *The conceptual linkages among local, provincial and national plans and frameworks, highlighting the regional frameworks as a key integrator and coordinator of the various policies*

*for key functional regions (copied from the Greater Cape Metro Regional Spatial Implementation Framework (Department of Environmental Affairs and Development Planning 2019)).*

Summarizing the Greater Cape Metro Regional Spatial Implementation Framework and associated policies would be too much to include in this proposal, but we highlight some of the key emergent issues affecting the development pathway of the proposed landscape below.

**Groundwater management and abstraction**

This is discussed in more detail throughout in the proposal, but the region's increasing dependence on groundwater for domestic and bulk water supply creates a number of challenges and research requirements around managing the resources responsibly, minimizing negative, and maximizing positive impacts on the various interconnected social ecological systems. Key issues for managing the TMG aquifer are narrowing the uncertainty and monitoring of recharge, stored volumes, flow paths and residence times, while improving our understanding of groundwater dependent species and ecosystems and minimizing the potential impacts of abstraction. In the lowlands, the biggest issue facing the CF aquifer is managing pollutants and water quality, which requires engaging with the complex feedbacks with and among the natural, canalized and piped surface waters and the communities and management structures that influence them. This is an incredibly challenging space, but is part and parcel of transitioning to a water sensitive city and has great potential for many positive social and ecological outcomes.

**Water Sensitive City**

Commitment number 5 of the CoCT Water Strategy (2019) is to transition to a Water Sensitive CIty by 2040. This represents a significant paradigm shift in urban water and related environmental resources management and the way in which it is integrated into planning and design of cities and towns. While the Water Strategy broadly emphasises key areas of focus such as water sensitive urban design (WSUD), upgrading ageing WWTWs, exploring the possibility of capture and storage of stormwater runoff and improving the liveability of urban waterways, the strategy that will facilitate a Water Sensitive transition remains unpublished. One challenge identified in this transition is the mismatch between hydrological and administrative boundaries (Serrao-Neumann et al. 2019). This is where our alignment to regional planning and implementation framework (e.g. Department of Environmental Affairs and Development Planning 2019) is clearly justified: city-regions are considered an appropriate scale for strategic planning and implementation of development policies (Rodríguez-Pose 2008). It has been suggested (Serrao-Neumann et al. 2019; Vietz et al. 2016; Plummer et al. 2011) that urban water resources should be managed at such a scale and that it may be difficult to transition towards a Water Sensitive City without holistic understanding of water systems as integrated hydrological and anthropogenic systems at the city-region scale (Serrao-Neumann et al. 2019). This proposed research platform is well positioned to align and support the research needs of this transition.

**Collaborative governance and restoration of ecological infrastructure**

Stakeholders and various levels of government are increasingly realising that collaborative governance and stewardship (careful and responsible management) are needed to maintain the value gained from ecological infrastructure (Chapin et al. 2010). Environmental governance cannot only be driven by policy set at higher levels. Government struggles to fulfill their compliance and regulation mandates due to lack of resources and/or coordination among different wings of government, and balancing the competing demands of different stakeholders, communities, and regions, often resulting in poor environmental outcomes. Governance structures and cultures at local and regional levels need to play a role in long-term solutions (Folke et al. 2011). This seems increasingly tangible as companies shift their social-environmental ethic from a focus on compliance at minimal short-term financial cost to starting to meaningfully redefine their purpose as organisations in the wider social and environmental context and over longer time-horizons, looking to optimise their delivery of social and ecological value. This bolsters collective responsibility for working together with many different stakeholders to find solutions to complex problems. The Greater Cape Town Water Fund public-private partnership (detailed in the next section) is a good example of this, as is Co-Go (the Collaborative Governance co-operative, that evolved from the Stellenbosch Rivers Collaborative). The Western Cape government's Ecological Infrastructure Investment Framework (EIIF; DEA&DP in prep) aims to provide an enabling environment for more of these kinds of initiatives, which, bolstered by the United Nations (UN) General Assembly declaration of 2021–2030 as the *UN Decade on Ecosystem Restoration* could see major benefits for the environment and provide for a rich social-ecological research space.

**Alien Invasive Species Management**

As mentioned in under coupled terrestrial and aquatic systems, invasive species are having significant impacts on the water budgets of catchments in the region and these are projected to become much worse if not contained (Le Maitre et al. 2019). Initiatives including the Greater Cape Town Water Fund (Stafford et al. 2019), the Working for Water programme and the proposed Ecological Infrastructure Investment Framework (EIIF; DEA&DP in prep) are investing significant effort in this regard. Their success, or failure, will see significant land cover change, especially in the upper catchments, with profound implications for water, fire, biodiversity and other ecosystem services.

Beyond impacts on water, a major challenge will be addressing the impacts of nitrogen fixing *Acacia* species on nutrient cycles. They are known to have impacts on the overall nitrogen and phosphorous budgets of these catchments and riparian zones. *Acacia spp* are known to be highly competitive in nutrient-poor Mediterranean type ecosystems such as fynbos as they are able to effectively acquire nutrients (Morris et al. 2011) owing to their strong $N_2$-fixation abilities (Levine et al. 2003). *Acacia spp* have been observed to have a competitive advantage over leguminous fynbos species *Virgilia* as they are able to utilise higher levels of atmospheric $N_2$ when N and P in the soil are limiting (Esterhuizen et al. 2020). (Stock, Wienand, and Baker 1995) found that *A. saligna* relied almost completely on symbiotic $N_2$ fixation. The $N_2$-fixation capability of *Acacia* spp has been observed to alter nutrient cycling regimes (N and P) of mountain and foothill sections of fynbos riparian ecotones (Naude 2012). This research also found that in areas formerly occupied by $N_2$-fixing *Acacia* species, inorganic N remained double the natural levels >7 years after clearance, with observed lower fynbos diversity and homogeneous communities (Naude

2012). Restoring lands that carry the burden of *Acacia* invasion legacies is very challenging, requiring significant effort at considerable cost (P. M. Holmes et al. 2020). There is a renewed effort underway by CapeNature and DEFF to search for more effective and efficient ways of ridding invaded areas of invasive plant species that may shift the financial and time burden required to effectively manage these species.

**Urban Densification: Inward growth**

Of particular relevance to the lower catchments, is the regional agenda to shift from an 'outward' to an 'inward' urban growth trajectory. "*The region's spatial growth trajectory is unsustainable, particularly with regard to its extensive ecological footprint and its vulnerability to escalating risks (e.g. drought, fires, air pollution, congestion). These diseconomies of scale detract from environmental health, and compromise the region's comparative advantage in the agricultural and tourism sectors. The RSIF presents a regional agenda for shifting from an 'outward' to an 'inward' urban growth trajectory.*" (Department of Environmental Affairs and Development Planning 2019)

Planned increases in urban densities (Department of Environmental Affairs and Development Planning 2019; City of Cape Town 2018b) will have implications for water, carbon and nutrient budgets and their flux rates into and out of these watersheds and landscapes. Water, Carbon and nutrient budgets for urban watersheds are a complex interaction of natural and human mediated inputs, outputs and processes. For example, in terms of nitrogen, natural inputs into the system such as $N_2$ fixation, wet and dry deposition and surface/groundwater inflows are often dwarfed by human mediated inputs which include food imports, fertilizer and NOx emissions from the burning of fossil fuels (e.g. Hobbie et al. 2017; Atkins, Anderson and Haskins n.d. in prep). The fate of this anthropogenically derived N is largely unquantified but pathways include surface water runoff (which includes WWTW effluent), agricultural crop yield and denitrification. For the most part, excess N in the system will likely be discharged from the urban catchments into False Bay as both surface and groundwater. However, the magnitude and nature of N accumulation and cascades (Galloway et al. 2003) in these urban catchments are not well researched. Understanding the variability of N budgets across the urban landscape, over time and in response to particular urban planning and design practices may address some of the challenges in urban water quality management. The role of wetlands and riparian zones (albeit highly modified) in carbon and nutrient budgets (and their ratios) of these urban catchments remain unquantified, as are the critical thresholds of these ecosystems. The magnitude and nature of catchment N budgets may highlight the important ecosystem services provided to the City by these ecosystems.

### Changing agricultural practices

The increasing pressures on agriculture from changing temperature and rainfall regimes (Vink et al. 2012) and rising demand require a change in agricultural practices (Halpern and Meadows 2013; Ziervogel et al. 2014). There are several non-mutually exclusive responses that may allow agriculture to persist sustainably. There is a widespread promotion of Climate Smart Agriculture (https://csa.guide/) and other strategies such as precision agriculture and conservation agriculture which are efforts towards sustainable farming. The Western Cape is implementing Smart Agriculture for Climate Resilience (SmartAgri) priority projects which include *Conservation Agriculture for all commodities and farming systems* (https://blwk.co.za/).

Conservation Agriculture is an approach that endeavours to achieve long-term sustainability through improving soil health through minimum soil disturbance, maintaining organic content and associated nutrients and using diverse and rotating crops (see FAO Conservation Agriculture website: http://www.fao.org/ag/ca/1a.html). Conservation Agriculture is also seen as a potential strategy for climate change adaptation. However, there is a need for more accurate approaches on how conservation farming is promoted, monitored and evaluated (Findlater, Kandlikar, and Satterfield 2019). Conservation Agriculture in combination with precision agriculture may yield valuable results for long term implementation. The proposal provides an opportunity to track Conservation Agriculture impacts on critical soil quality parameters such as soil organic matter (SOM), soil biodiversity and infiltration (Six et al. 2002), which may also help us understand whether Conservation Agriculture benefits translate into the greater catchment level.

Precision agriculture uses technology such as remote sensed imagery from satellites and drones or fine-scale temperature and soil moisture loggers to measure where and when agricultural activities and resources are required so that they can be applied optimally (e.g. Mulla 2013; Ncube, Mupangwa, and French 2018). This approach is particularly apt in the heterogeneous environment around the Greater Cape Town area (e.g. Wallace 2018) and will require more monitoring and research to implement fully. The Western Cape Department of Agriculture has been funding FruitLook since 2011 (https://www.fruitlook.co.za/), in the process collecting valuable data that can be used in combination with data collected from the landscape to gain a better understanding of farming systems and environmental impacts such as drought.

Alternative crops that have wider thermal and water tolerances are a way of adapting to changing climate (e.g. Luedeling 2012) but the choice of these crops and their rotation will also need to be informed by good environmental data and future climate models and the changing socioeconomic environment.

Quaternary Catchments G22D and G22C share one of the largest urban agriculture sites within the Cape Metro, the Philippi Horticultural Area (PHA). The site is both an environmental and a socio-ecological hotspot. Recent studies indicate that PHA is under threat from a changing urban edge and rezoning of land from agricultural to mixed use, including developments and industry (Horn 2018, 2019). There are indications of accumulation of heavy metals in the PHA soils (Malan et al. 2018, 2015). The PHA is also seen as a valuable portion of farmland that contributes significantly towards food security in and around the PHA (Donn-Arnold 2019). The site is, therefore, important for assessing the socio-ecological implications of the changing land use.

## Natural ecosystems

The Cape has the second highest number of plant extinctions in the world after Hawaii (Humphreys et al. 2019), of which more than a third are from within the City of Cape Town's municipal boundaries (A. G. Rebelo et al. 2011). This probably makes it the plant extinction capital of the world. We don't have good numbers for other taxonomic groups, but there is no reason to believe they are doing much better. Unless most of the anticipated development pathways discussed above are implemented in a sustainable way in the immediate future it is expected that the current trends of habitat loss, habitat degradation and fragmentation in this area will continue (A. G. Rebelo et al. 2011; P. Holmes et al. 2012). Being able to quantify and mechanistically understand the loss and/or inform the maintenance of this biodiversity and the services it renders over the long-term, is critical for managing the landscape sustainably.

While some threats are shared by both upland and lowland ecosystems (e.g. invasive species and climate change), there are a number of key differences. The upland ecosystems are still mostly large, contiguous tracts of natural vegetation that are contained within protected areas and have relatively intact ecological processes. The lowland ecosystems are highly fragmented, many key sites are not protected, and are highly vulnerable to edge effects and the influence of human actions in the matrix such as fire ignition, spray drift from pesticides, and other pollutants. While the City has a clearly defined systematic biodiversity plan that aims to improve the management of existing conservation areas and identifies priority areas to bring into conservation, this is marred by conflicting policies, public indifference in the face of competing challenges, and lack of sufficient resourcing or political will (P. Holmes et al. 2012). Tracking the retention or loss and the ecological condition of these ecosystems, and identifying and testing management options, are priorities for the region and provide many research opportunities from purely ecological through to purely social. There are many historical datasets that provide the opportunity to develop long term records of change in these fragmented landscapes retrospectively, often building on previous postgraduate studies. For example, the SAEON Fynbos Node have identified resurveying vegetation releve's established by Charlie Boucher in the early 1980s as part of his PhD on the Cape Coastal Forelands (Boucher 1983, 1987) as a priority. Another example would be revisiting the wetland vegetation surveys performed by Fynn Corry in the early 2000s (Corry 2011), but there are many many more and they are not limited to ecological datasets only. Beyond retaining the remaining fragments and maintaining their ecological condition, other key actions and research themes in the lowlands are that of ecological restoration and urban biodiversity. There are a number of ongoing restoration projects working in lowland vegetation (e.g. the Critically Endangered Cape Flats Sand Fynbos and Peninsula Granite Fynbos at Tokai (G22D)) and riparian systems (Kuils and Eerste), with active postgraduate students at all four of the local higher education institutions.

Current threats in the uplands are varied, but predominantly relate to the impacts of invasive species, altered fire regimes, climate change, and the emerging threat of groundwater abstraction for bulk water provision. Fire exclusion has the potential to allow indigenous forest to invade fynbos ecosystems (Slingsby et al. 2020), while too frequent fires threaten fynbos species that slow mature and set seed (Raimondo et al. 2009). Invasive alien plant densities are alarmingly high, and difficult to contain, but the anticipated impacts on water, biodiversity and fire risk are potentially catastrophic should we fail to do so (van Wilgen et al. 2016; Kraaij et al. 2018; Le Maitre et al. 2019). We are just beginning to detect climate change impacts on the indigenous vegetation (Slingsby et al. 2017) and there is much yet to learn. Correlative studies of satellite-derived measures of productivity suggest that there is potential for faster fynbos vegetation growth with higher minimum temperatures, potentially reducing fire return intervals, with knock-on effects for biogeochemical cycles (Slingsby et al. 2014; A. M. Wilson, Latimer, and Silander 2015; Slingsby, Moncrieff, and Wilson 2020). There are many long-term ecological datasets that can be used to investigate these issues, but the sparse meteorological data and lack of understanding of the spatial variability in microclimates in these topographically complex mountains are a major constraint.

Lastly, the recent targeting of the TMG aquifer for bulk water supply provides a new and largely unknown threat for these ecosystems. Direct impacts of infrastructure development are relatively easy to predict or quantify (see **Figure 9**), but forecasting the potential impacts of abstraction is far more difficult because of the multiplicative uncertainties associated with complex hydrogeology and hyperdiverse ecosystems. Unpacking this puzzle will require close collaboration between hydrogeologists, ecologists and likely many other disciplines. Fortunately, we’re not starting from scratch and there is a history of more than a decode of ecohydrology monitoring sites run by the City of Cape Town and its consultants, and many other potential retrospective long-term datasets such as Erwin Sieben’s riparian and high altitude wetland (mire/fen) vegetation plots first surveyed on the turn of the millenium (Sieben 2003; Sieben, Boucher, and Mucina 2004).

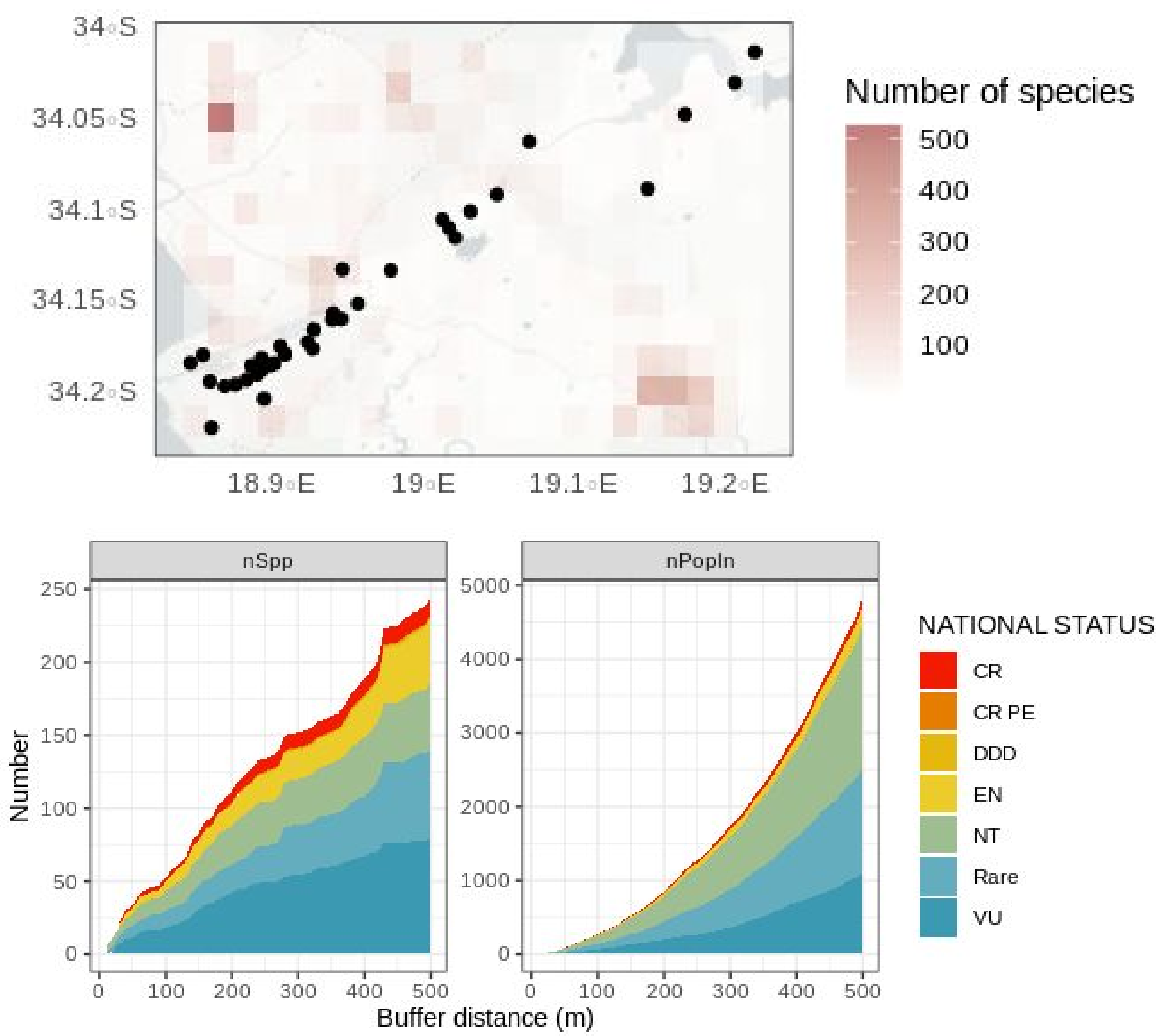



***Figure 9**: A map of the boreholes being established by the City of Cape Town from Steenbras (SW) to Theewaterskloof dam (NE) for bulk water abstraction from the TMG aquifer overlaid on a heat map of threatened species populations. The figures below show the cumulative number of species and populations of threatened species in the different threat categories intersected as one increases the buffer distance around the boreholes from 10 to 500m. The typical footprint of an individual borehole is approximately 1000m$^2$, but is highly variable in size and shape, and is usually associated with further impacts associated with the development of roads, power lines and pipelines (Slingsby in prep).*

## Logistical and operational suitability

### Security of tenure for the operations

The exact location of the core sites are up for discussion with the EFTEON leadership and stakeholders (see *Suitability for the deployment of micrometeorological observations* below), but the majority landowners (or custodians) are in strong support for the proposed landscape and are able to offer the core and satellite sites long-term (>20 years) stability and accessibility. These include the state entities CapeNature, the City of Cape Town and Stellenbosch Municipality (see the Stakeholder Analysis below and Letters of Support). All three have existing research permit authorization procedures and would allow access to sites for external researchers, and for deployment of additional long and short term research infrastructure. They are also open to negotiating memoranda of understanding or agreement to govern matters such as the security of operations and access to sites, data sharing, research authorization procedures, etc (as is done in the existing SAEON - CapeNature MoU). There are also other options such as farms and businesses, many of whom are already part of our stakeholder network, but these are probably better suited to satellite sites.

### *Existing facilities for hydrological observations*

This is largely covered in the table below on *Existing long-term observations and experiments*. There are a very large number of gauging weirs, dams and boreholes within the landscape (see **Map 2** and https://fynbos.saeon.ac.za/dashboards/efteon/). Inspecting all gauging stations in the field was not feasible within the timeframe allotted to preparing the landscape proposals, but most are known to be operational. For example, the most recent data reported by those operated by the National Department of Water and Sanitation can be viewed through their online data systems, which suggests that most are operational. There are also a large number of closed stations within the landscape (not on map) that could be reinstated, and the Greater Cape Town Water Fund has a 2019 report commissioned from Aurecon that details the potential for further streamflow gauging in the upper portions of catchments G40C and H60A.

## Suitability for the deployment of micrometeorological observations

The landscape already has the well-established Jonkershoek observation platform, complete with eddy covariance system, run by the SAEON Fynbos Node. This provides a “natural” land cover site with relatively intact ecological processes and ecological and hydrometeorological data going back 90 years. The first year of flux data suggest that the Jonkershoek eddy covariance site is suitable for long-term observation, although the data collected so far need to be verified as the instrument will only be field-calibrated for the first time in October. Other instrumentation and observations can be added to match the EFTEON design. This automatically ticks the core “natural” site requirement for comparison to other EFTEON landscapes. It also provides the opportunity to be creative with the deployment of the EFTEON instrumentation, allowing comparisons such as between natural and transformed (or transforming) ecosystems, variation within natural ecosystems (e.g. high vs low elevation, wetland vs terrestrial), or even to have a roving EC system that can be moved to sample and characterize different land use/cover or ecological settings. There are more than enough options within the landscape to ensure that the sites sampled meet the assumptions of horizontal heterogeneity and steady state conditions. Depending on the land cover types we aim to sample the sites would most likely be within the extensive protected area network or municipal land, but there are also many “research friendly” farmers that help ensure that all major land cover types could be sampled. Lastly, given that the Jonkershoek EC station is relatively new, the SAEON Fynbos Node are also open to moving the existing instrument to provide the best representivity or juxtaposition of micrometeorological observations within the landscape.

## Existing long-term observations or experiments

An exhaustive review of existing long-term research and experiments within the proposed landscape would be a long-term research project in its own right. To simplify, we have included a table of some of the existing observations, experiments and research arranged by major EFTEON theme below. Please note that this does not include the huge and varied treasure trove provided by the innumerable research programmes and student theses associated with the four higher education institutions in the landscape.

While there are a large number of existing formal experiments, we should also highlight the potential for "natural experiments" resulting from the various anticipated development pathways within the landscape, from urban expansion or densification through to ecological restoration initiatives.

The very active citizenry in terms of citizen science initiatives and civil society organizations within the landscape will be a major boon for enabling engaged participatory research at scale within the landscape. There is also great potential for working with schools, building on existing school engagements such as the SAEON education programme, the Freshwater Research Centre's Living Labs outreach programme, and the Ingcungcu Sunbird Restoration Project (which is planting "nectar gardens" of indigenous plants at schools to encourage mobility of indigenous avifauna through the urban landscape), among others.

| Theme | Responsible Institution/ Organisation | Observations | Comment |
|---|---|---|---|
| Atmosphere | SAAQIS | Summary air quality indicators | https://saaqis.environment.gov.za/ |
| | CoCT | Various air quality measures. See document for details. | http://resource.capetown.gov.za/documentcentre/Documents/Graphics%20and%20educational%20material/Water%20quality%20-%20assurance%20through%20testing%20.pdf.pdf<br><br>Some is available through the City's open data portals (https://web1.capetown.gov.za/web1/opendataportal/Default https://odp-cctegis.opendata.arcgis.com/)<br><br>More is available directly from the City of Cape Town and its contractors by research application request. We would hope |

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| | | | to negotiate an MOU or data user agreement in this regard as per the Department's letter of support. |
| | SAWS | Meteorology | By research request. |
| | | Cape Point Global Atmospheric Watch (GAW) station | Freely accessible through the World Data Centre for Greenhouse Gases |
| | SAEON | Meteorology | https://fynbos.saeon.ac.za/ |
| | ARC | Meteorology | http://www.arc.agric.za/arc-iscw/Pages/Climate-Monitoring-Services.aspx by request |
| | CapeNature | Meteorology | By research application request. We would hope to negotiate an MOU or data user agreement in this regard as per their letter of support. |
| Biogeochemistry | CoCT (Scientific Services) | Water quality | Some is available through the City's open data portals (https://web1.capetown.gov.za/web1/opendataportal/Default https://odp-cctegis.opendata.arcgis.com/) More is available directly from the City of Cape Town Department of Water and Sanitation and its contractors by research application request. We would hope to negotiate an MOU or data user agreement in this regard as per the Department's letter of support. |
| | Future Water | Water Quality, Flow rates | http://www.futurewater.uct.ac.za/ |
| | BIOGRIP | Water quality in the False Bay marine environment | https://sarahefawcett.wordpress.com/research/false-bay-water-quality/ |
| Hydrology | CoCT | Borehole location and water level, | Some is available through the City's open data |

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| | | especially for the TMGA wellfields (Steenbras and Nuweberg) and Cape Flats Sand Aquifer (CFA) within the landscape.<br><br>Surface Water - various, including dam levels and flow rates for Steenbras and other City-owned bulk water schemes (e.g. minor dams on Table Mountain, transfer pipes, etc).<br><br>Estuaries and wetlands | portals (https://web1.capetown.gov.za/web1/opendataportal/Default https://odp-cctegis.opendata.arcgis.com/) More is available directly from the City of Cape Town Department of Water and Sanitation and its contractors by research application request. We would hope to negotiate an MOU or data user agreement in this regard as per the Department's letter of support.<br><br>http://resource.capetown.gov.za/documentcentre/Documents/Project%20and%20programme%20documents/Chapter%2023%20-%20Estuary%20Management%20Plans.pdf |
| | DWA | Various stations gauging streamflow rates, groundwater levels, water quality, etc | http://www.dwa.gov.za/Projects/NWRM/documents.aspx<br><br>http://www.dwa.gov.za/Hydrology/default.aspx |
| | DA Cape Farm Mapper | Water Resources, Soils, Rainfall, Evapotranspiration, Groundwater, General Climate, | https://gis.elsenburg.com/apps/cfm/ |
| | SAEON | Hydrometeorological observations at Jonkershoek (>90 years) and on the Cape Peninsula (~8 years).<br><br>Extensive data on the estuaries. | https://fynbos.saeon.ac.za/<br>https://saeis.saeon.ac.za/<br>https://sancor.nrf.ac.za/Shared%20Documents/Reports%20documents/SANCOR%20Occasional%20Report%20No%207.pdf |
| | The Greater Cape Town Water Fund | Streamflow monitoring, land cover | https://public.tableau.com/profile/waterfunds#!/vizhome/GCTWFDSSv1/Implementation and/or by request from The Nature Conservancy |
| Biodiversity | iNaturalist | >250 000 observations of >7900 | https://bit.ly/3n21olq |

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| | | species by >4500 citizen scientists!!! | |
| | Freshwater Biodiversity Information System (FBIS) | Fish, invertebrates, algae, SASS scores, and more | https://freshwaterbiodiversity.org/ |
| | Cape Nature | Population monitoring of Proteaceae, select threatened plants, amphibians, freshwater fish and distribution data for vertebrates.<br>Fire | By research application request, although much data is available via FBIS or SANBI |
| | SANParks | Various | https://www.sanparks.org/scientific-services/nodes/cape-research-centre |
| | CoCT | City of Cape Town's Biodiversity Network, urban tree canopy map, species occurrence records, habitat condition surveys | http://bgis.sanbi.org/capetown/bionetwork.asp |
| | SANBI | Various, from species occurrence records to National Vegetation Map, National Vegetation Database (vegetation survey plots), land use decision information, fire records, etc | https://newposa.sanbi.org/<br>http://bgis.sanbi.org/ |
| | SAEON | Vegetation survey plots, demography of Proteaceae, satellite remote sensing.<br><br>The archives of the Jonkershoek Forestry Research Centre, which operated beyond Jonkershoek to include many other catchments and perform a variety of studies including vegetation surveys, population and veld assessments, soil surveys, etc. These data have all been scanned and metadata created. A data paper describing the dataset is in preparation. | https://fynbos.saeon.ac.za/ |

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| | FitzPatrick Institute of African Ornithology | Citizen science databases on occurrence of birds and other taxa - South African Bird Atlas Project (SABAP2), coordinated waterbird counts (CWAC), virtual museum, SAFRING | http://sabap2.birdmap.africa/<br>http://safring.birdmap.africa/<br>http://cwac.birdmap.africa/<br>http://www.vmus.africa/ |
| Social - ecological - technical | DEA&DP | Various - from policy documents to raw data | https://www.westerncape.gov.za/eadp/about-us/spatial-information-management |
| | CoCT | Multiple open source data: e.g. Demography and Statistics, Economic development, Land administration, Boundaries, human settlements, spatial planning, 8 cm colour-infrared aerial imagery, LIDAR, piped infrastructure networks. | https://web1.capetown.gov.za/web1/opendataportal/Default<br>https://odp-cctegis.opendata.arcgis.com/ |
| | WC Department of Agriculture (Cape Farm Mapper) | Agricultural, Agri-Infrastructure and Tourism, Smart-Agri, Remote sensed imagery | https://gis.elsenburg.com/apps/cfm/ |
| | Centre for Complex Systems in Transition (CST) | Various - see website | https://www0.sun.ac.za/cst/research/ |

## Office and other facilities for operations and staff and guest researchers

It is envisaged that the EFTEON operations would be hosted by the SAEON Fynbos Node, who conduct similar operations and thus have similar requirements in terms of lab space and other facilities. The SAEON Fynbos Node is currently hosted by SANBI at Kirstenbosch, who have all the necessary facilities, although we will need to negotiate more office space.

In the longer term, the SAEON Fynbos Node are hoping to build a new building at the South African Astronomical Observatory (SAAO), which could also house the EFTEON staff. There are also discussions around centralizing all Cape Town based SAEON operations including the uLwazi, Egagasini and Fynbos Nodes, the SMCRI Two Oceans Sentinel Site and SAPRI, and the EFTEON staff could easily be included. There is also potential for the EFTEON staff to be housed by CapeNature or any of the educational partner institutions (see Academic setting).

In terms of residential facilities for staff and guest researchers, accommodation, schools, hospitals, potential employment for spouses et cetera, these are all easily covered within the Greater Cape Town Area. In fact, the desirability of living in the area would be a major advantage for attracting high quality EFTEON staff. Similarly, the international airport and road networks (including to mountain peaks) facilitate easy access to sites by EFTEON staff and visitors. While there may be potential safety and security concerns for some areas within the landscape, the City of Cape Town and others have staff operating at these sites and can advise as to safety protocols and procedures if needed.

## Stakeholder analysis

The analysis of stakeholders in a landscape of this size, complexity and dynamism will have to be an ongoing process and should perhaps be formally included in the SES component of the landscape. Given both the timeframe within which the proposal was developed, the constraints imposed by the pandemic on holding in-person meetings and workshops, and the general strain and fatigue that has been affecting many during this time, it will be essential that there be further workshopping, stakeholder and community engagement (that adheres to the ethics protocols of the lead research institutions) and planning prior to the deployment of instrumentation and collection of other observations. That said, we have managed to engage with a large number of stakeholders and canvas considerable support and engagement throughout the development of this proposal that acts as a strong foundation with which to continue further inclusive engagement.

Our partner networks also provide useful platforms on which we can build. For example, The Greater Cape Town Water Fund has done extensive stakeholder engagement around investment in and implementation of restoration of ecological infrastructure, which ties together almost all the key stakeholders in the upper catchments and many in the lower catchments. In the lower catchments, our partnership with the Collaborative Governance (Co-Go) initiative (which builds on the Stellenbosch River Collaborative) will allow us to learn lessons from and leverage the gains they have made in the seven years that they have been working in the Eerste River and associated catchments.

We acknowledge the complexity of undertaking social research in African urban settings and the need to be inclusive and adaptable. van Breda and Swilling (2019) emphasise that the study of urban sustainability transitions needs to adopt research methods that are nimble and able to adapt as research unfolds. They term this emergent transdisciplinary research, and while such novel methods are known to be time consuming and often challenging, they make for more context-appropriate research and are premised on clear research questions and good working relations with local communities. These specifics will only emerge once research is underway.

This landscape has vast support from landowners and land custodians, academic institutions, researchers, NGOs and other bodies, supporting the development of the research infrastructure. These are evident in the section on Academic setting, the list of participants and letters of support and include:

***Landowners/custodians/partners:***
CapeNature
City of Cape Town, Environmental Management
City of Cape Town, Water & Sanitation
South African National Parks
Stellenbosch Municipality (letter of support pending)
The Nature Conservancy (Greater Cape Town Water Fund)
Collaborative Governance (Co-Go) Network for Water Security

***Government***
National Department of Water & Sanitation
Western Cape Department of Agriculture
Western Cape Department of Environmental Affairs and Development Planning

***Local academic institutions and research groups***
University of Cape Town, Department of Oceanography, Biogeochemistry Lab

University of Cape Town, Statistics in Ecology, Environment and Conservation (SEEC)
Stellenbosch University Water Institute (SUWI)
University of Cape Town, Future Water Institute
University of the Western Cape, Department of Earth Sciences
Cape Peninsula University of Technology, Centre for Water and Sanitation Research
University of Cape Town, African Climate & Development Initiative (ACDI)
Stellenbosch University, Centre for Complex Systems in Transition (CST)
Centre for Invasion Biology (CIB)
University of Cape Town, Climate System Analysis Group (CSAG)
Stellenbosch University, Department of Conservation and Entomology
ASSET Research
Southern African Programme for Ecosystem Change and Society (SAPECS)
South African National Biodiversity Institute (SANBI)
South African Weather Services (SAWS)
Freshwater Research Centre (FRC)

***International academic institutions and research groups***
Central Arizona-Phoenix Long-Term Ecological Research Program, Arizona State University
NATURA
The Pacific Institute, Oakland, CA, USA
University at Buffalo, New York, USA (NASA BioSCape Campaign)

***SARIR Projects***
Shallow Marine and Coastal Research Infrastructure (SMCRI)
Biogeochemistry Research Infrastructure Platform (BIOGRIP)

***NGOs and other***
Botanical Society of South Africa
Kogelberg UNESCO Biosphere Reserve
Winelands Fire Protection Association
Umvoto Africa

## Summary of proposed scientific and societal objectives

***Themes: All of which can/will be approached from a SES perspective***

*Water*

- *Climate change impacts on strategic water source areas (surface and groundwater)*
- *Surface and groundwater dynamics and interactions (recharge, pollution, groundwater dependent ecosystems)*
- *Catchment restoration and protection*
- *Land use/cover and water flows from source to sea*
- *Land use/cover and nutrient/pollutant flows from source to sea*

*Social and Environmental Justice*

- *Environmental governance*
- *Air quality*
- *Water quality*
- *Sustainable agriculture*
- *Urban greening*
- *Urban heating*
- *Access to green space*
- *Restoration and investment in ecological infrastructure*
- *Urban planning (or lack thereof) and*
    - *Expansion (formal and informal) vs ecosystem services*
    - *Vulnerability to ecological and other processes (fire, flood, storm surge/sea level rise, erosion)*

*Biodiversity and Conservation*

- *Connecting people and biodiversity*
- *Climate impacts on biota*
- *Invasive alien plant impacts on biota*
- *Atmospheric deposition impacts on biota*
- *Altered fire regimes and impacts on biota*

- *Habitat fragmentation impacts on biota*
- *Groundwater dependence of species and ecosystems*
- *Potential impacts of groundwater abstraction*
- *Successes and failures of restoration initiatives*
- *Urban biodiversity*

*Climate Change and Futures*

- *Improved high elevation climate observation*
- *Altered weather patterns*
- *Carbon budget and fluxes of*
    - *natural and human-altered terrestrial and freshwater ecosystems*
    - *a shifting baseline for "natural vegetation"*
- *Urban heating*

*Adaptation & Resilience*

- *Restoration and/or investment in ecological infrastructure*
- *Resilient utility provision*
    - *Water sensitive City*
- *Just transitions to sustainability*

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