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Enhancing the relationship between urbanization, environmental assets and ecosystem services

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with support from The Nature Conservancy

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PREFACE AND ACKNOWLEDGMENTS

This study forms one of the case studies of a larger study on Green Urban Development commissioned by the World Bank and co-funded by The Nature Conservancy. Anchor Environmental Consultants (Anchor) was subcontracted by AECOM to undertake case studies in three cities: Kampala, Uganda; Dar es Salaam, Tanzania; and Durban, South Africa. Each city was consulted as to the focus of the case study. In the case of Durban, the city requested a study to evaluate Durban's natural capital and its role in Green Urban Development (GUD). The study is made up of two parts. The first part provides an updated, spatial estimate of the value of natural capital in the eThekwini Municipal Area and the second part is a scenario analysis that evaluates the potential returns to investing in GUD with a focus on the role of natural systems. This study builds on the preparation of an Environmental Profile for eThekwini Municipality by AECOM.

The ecosystem valuation study was led by Dr Jane Turpie and Gwyn Letley of Anchor Environmental Consultants. Dr Robynne Chrystal and Prof Derek Stretch of CCS consulting undertook the hydrological modelling work, and Dr Stef Corbella of CCS consulting prepared the engineering cost estimates. Grant Benn assisted with the GIS aspects of the study.

We are grateful to the eThekwini municipal staff for their interest and support of this project, in particular to eThekwini Municipality Real Estate Department for supplying the property transaction data and to the eThekwini Environmental Planning and Climate Protection Department for providing relevant GIS data and associated explanations for the Durban Metropolitan Open Space System.

Thanks to Roland White and Chyi-Yun Huang of the World Bank and Diane Dale, Brian Goldberg and John Bachmann of AECOM for inputs and discussions during the project, and to Dr Timm Kroeger of TNC, Jeff Wielgus (independent), Mike Toman of World Bank, and Sanjay Strivastava of UNEP for inputs during the study and comments on an earlier draft.

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EXECUTIVE SUMMARY

Introduction

It is increasingly appreciated that ecosystems can make a significant contribution to human welfare through the provision of raw materials and food, functions that influence air and water quality, climate, hydrology and the abundance of useful and harmful organisms, and the provision of opportunities for recreation and entertainment, spiritual fulfilment, cultural, educational and scientific activities. While these ecosystem services are mostly associated with natural systems outside of cities, including the services provided to cities such as water quality amelioration, they can also be provided by the natural systems occurring within urban areas. In fact, urban ecosystems provide important amenities and contribute to the livelihoods and wellbeing of large numbers of people, and ultimately to the resilience of cities. However, especially in developing countries, natural urban open spaces are rapidly becoming degraded or lost as a result of high rates of urbanisation and a lack of city finances to retain and manage them.

Durban is located within a global biodiversity hotspot, and still contains a wealth of biodiversity. Some of this is protected in nature reserves, but much of it is in private hands or in communal lands on the city's periphery. City managers are divided over the level of attention that should be given to preserving these remaining natural areas. While it is argued that they make a significant contribution to biodiversity conservation in the province, provide valuable ecosystem services and will contribute to the city's resilience in the face of climate change, the counter argument is that much of this area should make way for development to alleviate the escalating problem of unemployment. In the meantime, managers of these natural areas have to make do with a very small percentage of the city's budget, reflecting the current priorities of the city.

The study of ecosystem services and their value to society has made significant advances since an estimate was made of Durban's ecosystem services in the 1990s using early values from the international literature. This has been partly due to the advent of vastly improved spatial data which allows a better understanding of geographic variation in the supply of and demand for ecosystem services. However, relatively little work has been done on the role and value of ecosystems within urban areas, and most of this work has been limited to single types of services or value.

The aim of this study was to provide estimates of the value of ecosystem services provided by natural open space areas within the eThekwini Municipal Area (EMA), and to map the geographic variation in these values as far as possible so as to be able to compare both areas and types of value, using available and locally-relevant data.

The Millennium Ecosystem Assessment classified ecosystem services into provisioning, regulating, cultural and supporting services. The values of these services are generally described using the Total Economic Value framework, which classifies values into direct use, indirect, option and non-use values. Economic value of any asset or service can be defined in terms of the amount that people are willing to pay for it. Economic welfare is a measure of the total benefit that society derives from economic transactions, and is the sum of the net benefit to consumers (consumers' surplus) and the net benefit to producers (producers' surplus). Since some ecosystem services are not directly traded in markets, environmental economics has developed a suite of methods to value the non-market benefits of ecosystems and environmental quality.

This study was carried out as a desktop study based on available data. Modelling assumptions were based on data from within the study area, drawing on the regional, national or international literature only where necessary. The study focused on the direct values associated with the provision of natural resources, indirect use values associated with regulating services generated by ecosystem functioning, and the amenity values generated by ecosystem attributes. Estimation of option values and non-use values associated with ecosystems require survey-based methods and were beyond the scope of this study.

The eThekwini Municipal Area

The city of Durban is located in the eThekwini Municipal Area (EMA) in the province of KwaZulu-Natal on the east coast of South Africa. The EMA covers an area of just less than 2300 km2 extending from the uTongati River in the north to the aMahlongwa River in the south. The EMA is topographically diverse, characterised by winding river valleys and steep hills rising from the narrow coastal plain. The area has a subtropical climate with humid wet summers and mild dry winters, and a mean annual precipitation of over 1000 millimetres.

The EMA has a population of 3.44 million, the third largest of the six metropolitan municipalities in South Africa. This represents just over one third of the provincial population of KwaZulu-Natal (KwaZulu-Natal) and has been projected to rise to four million by 2020. While the EMA covers only 2.5% of the area of KwaZulu-Natal it accounts for 66% of provincial and 11% of national GDP.

The EMA encompasses the urban area of Durban (25% of the area) as well as significant peri-urban (30%) and rural land use areas (45%). Only 55% of households are in formal dwellings, with 34% in informal dwellings (concentrated in the peri-urban areas) and 11% in traditional or rural dwellings. The latter fall mainly in communal land areas administered by the Ingonyama Trust.

The EMA is situated in the centre of one of 34 Global Biodiversity Hotspots, the Maputaland-Pondoland-Albany region, and contains an impressive array of biological diversity. The natural assets of the EMA form part of the Durban Metropolitan Open Space System, or D'MOSS, which also includes agriculture, man-made parks and sports areas. The D'MOSS covers 75 000 ha, or almost a third of the total municipal area, above the high tide mark, and is under various types of ownership. The terrestrial landscape in the EMA is essentially a mosaic of open grassland, woodland, thicket, thornveld and forest. Much of this is degraded and very little falls within protected areas. The EMA also has a vast network of rivers and wetlands that drain into 16 estuaries along its coastline. The largest of these has been developed as Durban harbour, one of South Africa's most important ports. While most of the KwaZulu-Natal coast is a high energy environment, Durban central beaches are relatively sheltered and popular for recreation.

Provision of natural resources

The provisioning value of natural systems was estimated as the value of the sustainable yield of natural resources, up to the yield levels demanded. Terrestrial, freshwater and coastal ecosystems provide a number of living and non-living resources which are harvested for raw materials, food and medicine. In the eThekwini municipality these resources are predominantly harvested by poorer households on a subsistence basis or to generate some cash income. The greatest harvesting pressure comes from the rural communities that occupy the approximately 1500 km2 of rural areas in the hinterland of the EMA, as well as the people living in poor peri-urban communities, although markets for these resources will supply a much broader segment of the community, with some of the demand coming from both poor and relatively wealthy households within the urban area.

The types of resources that are harvested in the EMA include water for domestic use, reeds and thatching grass, firewood, poles, food plants, bush meat and fish. There are almost no data on the production or use of these resources within the study area. Provisioning values were estimated based on information on habitat productive capacity, actual harvests from comparable areas, habitat condition, land ownership, accessibility and proximity to main sources of demand. One of the commonly-used resources, sand, could not be supplied sustainably. Provisioning services were estimated to be worth in the region of R100 million per annum, with a net present value of approximately R1.12-1.46 billion. Most of the value is made up by water and fuelwood.

ES Table 1 Estimated extent and cost of the proposed GUD interventions

Natural Resource	Value (R millions)	% of total
River water for domestic use	31.8	32.5%
Fuelwood	46.5	47.5%
Timber poles	6.6	6.7%
Medicinal plants	4.7	4.8%
Grass and reeds	1.4	1.4%
Wild meat harvesting	0.6	0.6%
Fishery resources	6.3	6.3%
Total	97.9	

Carbon sequestration

Climate change caused by increases in the atmospheric concentrations of greenhouse gases will carry an estimated cost of about 2 – 7% of Gross Domestic Product (GDP) in different parts of the world by 2050, with developing countries being expected to incur proportionally greater costs. Natural systems can make a significant contribution to global climate regulation through the sequestration and storage of carbon. When they are degraded or cleared, much of this carbon is released into the atmosphere. These emissions contribute to global climate change, which is expected to lead to changes in biodiversity and ecosystem functioning, changes in water availability, more frequent and severe droughts and floods, increases in heat-related illness and mortality, and impacts on agriculture and energy production.

Based on a previous field-based study conducted in the EMA, the total amount of carbon stored in all the major vegetation types of the EMA open space system is estimated to be 6.6±0.2 million tonnes of carbon equivalent, or 24.3±0.9 million tons of carbon dioxide equivalent, and some 8 400 – 9 800 tonnes of carbon are sequestered per annum. The global damage costs that this amount of carbon could produce are over R9.8 billion, while the damage costs to South Africa resulting from a loss of the carbon stocks within the EMA would be approximately **R34.3 million per annum**. These avoided damage costs are the annual value of the service. The net present value of this service is estimated to be about **R393-511 million**.

Fisheries support (nursery value)

Estuaries provide nursery areas for numerous fish species that are exploited by recreational and commercial fisheries in the inshore marine area. The estuaries in the EMA support several species of fish caught in marine areas that are dependent on estuaries as nursery areas for at least their first year of life. Some of the larger estuary systems, such as the uMngeni Estuary, are also known to provide an important nursery habitat for penaeid prawns.

Based on the estimated value of the fisheries and the percentage contribution of estuary-dependent fish, the estimated total contribution of estuaries to KwaZulu-Natal coastal and inshore marine fisheries is R106.8 million per annum. Based on the sizes and relative health of KwaZulu-Natal's estuaries, it was estimated that the overall contribution of estuaries in the EMA is **R11.4 million per annum**, with a net present value of **R131-170 million**. This represents 11% of the contribution of nursery value in KwaZulu-Natal. uMkhomazi, Durban Bay, oHlanga and uMngeni have the highest percentage contributions and associated nursery values. Estuaries that are both small and severely degraded, such as the iSipingo and Little aManzimtoti, contribute very little. It was estimated that two thirds of the value that the EMA estuaries could provide to KwaZulu-Natal fisheries if they were in a high quality state has been lost.

Agricultural support (pollination)

Natural habitats support organisms that provide agricultural support services in the form of pollination and the control of agricultural pests. Crop pollination by insects is an essential ecosystem service that increases both the yield and the quality of crops. Of the crops grown within eThekwini Municipality, many are wind-pollinated, including sugar and maize. However, several crops are directly dependent on insect pollination, including subtropical fruit crops such as mangoes, papayas, avocados and litchis, and nut trees such as macadamia, cashews and almonds. These crops are likely to benefit from wild colonies of bees occurring in untransformed vegetation around the tree crops or gardens, saving on active pollination costs incurred by hiring of bee hives or dusting.

The fruit tree crops and market gardens are located in small patches throughout the EMA, however the largest areas requiring pollination services are located predominantly in the outer-west and the northern planning regions. Assuming that these natural areas supply the equivalent service provided by three beehives per ha, the total cost of replacing the pollination service to 1144 ha of fruit and garden crops would be just over **R1 million per year** with a net present value of **R11.5-15 million**. Assuming relationships between vegetation characteristics and bee density, the highest potential pollination value is associated with vegetation patches in good condition that are surrounding market gardens and tree crops. Coastal and scarp forest and open grassland near agricultural areas could have a value of R65 - R90/ha/y, while thicket and woodland areas could be worth R130/ha/y.

Flow regulation

The combination of weather-related (e.g. rainfall intensity, extent and duration) and geophysical (e.g. catchment size, geomorphology, soil and land use) characteristics are the main factors that influence flooding (Kareiva et al. 2011). Natural systems such as wetlands and rivers or ecosystems with deep permeable soils can regulate flows through the landscape by slowing flows by means of storage and vegetative resistance and facilitating infiltration into soils. In this way these systems ameliorate the potential impacts of flood events by smoothing streamflow peaks, reducing bank and streambed erosion (Vellidis et al. 2003), as well as reducing the risk of damage caused by flooding of downstream areas.

For this study, a hydrological model was set up for the entire catchment area of the eThekwini Municipality using the PC-SWMM software. This model was set up to run design flood events in order to determine the influence of natural vegetation areas on flood hydrographs at strategic points relating to the location of existing flood conveyance infrastructure. The flood hydrographs generated under current conditions were compared with what they would be if the natural systems were transformed to urban land use. This provides an indication of the impacts of loss of natural areas on flooding and the difference can be construed as an estimation of the flood attenuation benefit obtained from (retaining) the natural systems. The additional flood volumes without these systems that would occur under different return period flood events (e.g. 1:10 years), would require larger drains, culverts, etc., depending on the size of the event these constructed flood management assets are designed to deal with. Thus a second model was developed in order to estimate the capital costs of the structures required under the present versus the without-vegetation scenarios. The difference, together with associated differences in discounted annual maintenance costs, is the total life-cycle flood management cost avoided by the natural systems, which can be converted to the net present value of the service.

The avoided capital cost requirements for flood conveyance were estimated to be R338 million. This represents a 0.7% - 3.5% capital cost saving in stormwater infrastructure. Including an estimated 6% of capital costs as an annual repair and maintenance cost (eThekwini Municipality 2015), this suggests that the flood attenuation service provided by natural systems in the EMA leads to a life cycle cost saving in the order of **R339 million** in net present value terms (equivalent to **R29.5 million per annum**). The highest per hectare values associated with D'MOSS are located in the catchments that are situated above the built up areas of Durban city centre and Durban North.

Sediment retention

Erosion and sedimentation within watersheds can become a major issue as it causes structural damage to reservoirs, causes flooding, affects the quality of drinking water and increases water treatment and maintenance costs at water treatment works. Vegetation can reduce erosivity by stabilising soils and intercepting rainfall, thereby preventing erosion. Vegetated areas, especially wetlands, also capture the sediments that have been eroded from agricultural and degraded lands and transported in surface flows, preventing them from entering rivers. While some level of sedimentation of dams is expected and planned for under natural conditions, elevated catchment erosion either incurs dredging costs or shortens the lifespan of dams and related infrastructure.

A hydrological model, set up using PC-SWMM software, was used to simulate the hydrology and sediment transport for the catchment area of the whole municipality. By comparing the modelled sediment outputs per catchment under current land cover versus fully transformed land use, it was possible to estimate the difference made by natural vegetation to the sediment loads transported to estuaries and the three main water supply reservoirs. The value of the service was then estimated for dams in terms of avoided replacement cost, based on modelled cumulative storage loss and for Durban Harbour in terms of avoided dredging cost.

The loss of vegetation cover from dam catchment areas leads to a significant increase in the rate of sedimentation, with the greatest impacts being felt by Hazelmere Dam. It was found that the replacement of these natural areas with human settlements could result in a nine-fold increase in sediments entering the dam. The total annual replacement cost associated with the loss in dam capacity as a result of sedimentation was estimated to be between R1.1 million and R2.9 million. This equates to a net present value of between R12.25 million and R33.03 million, with an average of R22.77 million. The annual TSS load into Durban Harbour increased by an estimated 195% when vegetation was removed and by 206% when the vegetation was replaced with dense settlement, resulting in dredging costs avoided of between R1.03 million and R1.15 million per year which translates to an average net present value of R12.5 million. Therefore the sediment retention service was valued at **R3.1 million** per year with a net present value of **R35.2-45.8 million**.

Water quality amelioration

Anthropogenic introduction of nutrients into the landscape can lead to reduced water quality and the eutrophication of freshwater and marine ecosystems. This reduces the capacity of these systems to supply ecosystem services and increases water treatment costs. Natural vegetated systems can play an important role in the trapping of sediments and absorption and breakdown of organic and inorganic pollutants in surface and sub-surface water runoff. Wetlands are particularly well known for their capacity for water quality amelioration, but the service is also provided by terrestrial landscapes. Phosphorus is removed through sediment trapping and plant uptake, nitrogen is removed through denitrification and plant uptake, and pathogens are destroyed by UV radiation.

In this study, the impacts of natural open space areas on water quality were estimated using a hydrological model which was set up to estimate the production and transport of total suspended solids (TSS), phosphorus (P) and total inorganic nitrogen (TIN) in the catchments of the EMA. The model was set up to estimate the change in sediment and nutrient loads entering dams and estuaries if the retention capacity of natural vegetation was eliminated (a hypothetical construct), or if natural vegetation was replaced with dense human settlement. These two scenarios provided the upper and lower bounds of the service provided by natural open space areas in physical terms. The value of the water quality amelioration service was then estimated in terms of the avoided costs to water treatment works and the avoided loss of estuary value as a result of the eutrophication of these systems.

Without the existing natural vegetation in their catchment areas, phosphorous loads entering the Inanda, Hazelmere and Nungwane Dams would increase by at least 193-319%, 193-968%, and 200 - 509%, respectively. Using these estimates and the water treatment cost models developed for Wiggins WTW and Durban Heights WTW it was estimated that maintaining the natural vegetation results in an annual saving of between R1 million and R8.68 million per annum, depending on the alternative land use.

It was estimated that maintaining the existing areas of natural vegetation also avoids potential losses in estuary fishery and nursery values of between R2.19 and R3.71 million per annum. Thus, overall, water quality amelioration services were estimated to be worth about **R7.8 million per annum**, with a net present value of **R89.1-115.8 million**. This is a conservative estimate as it does not take all affected downstream services into account. The highest per hectare values associated with D'MOSS are located upstream of Inanda and Hazelmere Dams, in the Durban Harbour catchment, as well as in the south of the EMA upstream of the Umkomaas, Msimbazi and Umgababa estuaries.

Amenity value to property owners

The amenity of green open space areas is reflected to a large extent in two markets that are observable – property and tourism. Urban residents often pay a premium to live close to the areas that they enjoy using, or to have a good view. Similarly, visitors pay to travel to and stay in an area where they will have access to or views of these amenities.

A hedonic valuation approach was used to estimate the value associated with different types of green open space within the EMA. Data on a total of 16 149 property sales over a two year period from January 2012 to October 2014 were analysed in relation to the amount and condition of each type of green open space within three distances of each property, as well as sea views and a range of other property, local population and neighbourhood characteristics. The results revealed that both the type and condition of open space have very important influences on property prices, with well-managed natural open space areas attracting significant and positive price premiums and those in a degraded condition resulting in lower property values. Well-managed green open space accounted for about 2% of overall property value, or **R4.4 billion**, while public parks attracted premiums amounting to 6.5% of property value, or **R13.8 billion**. These values were mapped to the relevant green open space areas, and suggest that well-managed open space areas and parks within the urban edge have an average asset value of R1.4 million and R20.5 million per ha, respectively, and jointly account for about R356 million per annum in property tax revenues to the city. The value of both types of open space areas was particularly high in wealthier neighbourhoods, possibly because of safety issues as well as ability to pay.

Tourism value

The year-round warm weather, extensive beaches and numerous outdoor activities make the city of Durban a leading tourism destination in South Africa. To determine the nature-based tourism value associated with open space areas in the EMA we used a large dataset of over 10 000 geo-tagged photographs uploaded to Google Earth's Panoramio site, based on the premise that the numbers of photographs uploaded to specific sites are correlated with the recreational value associated with these areas. The highest concentration of photographic uploads were associated with the Durban beachfront, Durban city centre, sports grounds and golf courses, protected areas, and shopping malls. Few photographs were taken in rural areas surrounding the main urban core of the EMA. Statistical analysis of these patterns in relation to the features of the different grid cells showed that the numbers of photographs were significantly influenced by the presence of certain land cover types, and that the interaction of man-made and natural features was important in determining the attractiveness of the latter.

The contribution of different attractions to tourism value were estimated by analyzing the content (or setting) of the photographs with each photograph being placed into one of five categories; (1) built environment, (2) natural open space, (3) man-made open space, (4) rural or agricultural, and (5) marine or coastal. The total value added by leisure tourism of R5.6 billion (based on a previous study) was then assigned to the five categories by relating the percentage breakdown of each category to the actual proportional land cover and the number of photographs within each grid cell in the EMA. Note that this is an underestimate of tourism value since it excludes consumers' surplus.

The total tourism value assigned to natural habitats (natural vegetation, freshwater systems, estuaries and the coastal environment) was almost R2 billion and accounted for 40% of all photographic uploads with the coastal environment contributing just over half of this value. Apart from beaches, natural areas with high values included Kranzkloof, Beachwood and Shongweni nature reserves, Umhlanga Lagoon, Durban Bay and uMngeni Estuary. Man-made open space such as parks and golf courses had a total leisure tourism value of R382 million at an average value of R234 000 per hectare. Therefore the combined tourism value of natural and man-made open space is approximately **R2.4 billion per annum**, with a net present value of **R27.5 billion**.

Summary and conclusions

Natural and semi-natural systems within the eThekwini Municipal Area give rise to flows of ecosystem services worth at least **R4.2 billion per year**. The total asset value of these areas was therefore estimated to be at least **R48 -62 billion** (ES Table 2).

The provisioning value natural systems was estimated to be R1.1-1.5 billion (NPV), with fuelwood and river water contributing the most to this value. Considering water is collected from rivers and streams by only 0.5% of the population in the EMA, this resource is thought to be the most valuable in terms of the service it provides per user household. The remaining values represent approximately R225-292 million of the total provisioning value of natural resources in the study area (ES Table 2). Regulating services have a net present value of about R1.0-1.2 billion with carbon storage and flow regulation accounting for 39% and 34% of this value, respectively. This value is believed to be a conservative estimate. The many benefits derived from these supporting services are indirect and particularly difficult to value, and most of the regulating services also play the role of supporting services that influence the outputs of other ecosystem services. The amenity value associated with natural and semi-natural open space areas in the EMA was estimated to be R45.7-59.4 billion, 96% of the overall value of ecosystem services (ES Table 2).

ES Table 2 Total value of ecosystem services in the EMA. Values in R millions (2015)

Ecosystem services	Annual Value (R millions)	NPV (20 y, 6%) (R millions)	NPV (20 y, 3%) (R millions)
Provisioning services			
River water for domestic use	31.8	364.7	474.1
Fuelwood	46.5	533.4	693.4
Timber poles	6.6	75.7	98.4
Food and medicinal plants	4.7	53.9	70.1
Grass and reeds	1.4	16.1	20.9
Bush meat	0.6	6.9	9.0
Fishery resources	6.3	72.3	94.0
Sub-total	97.9	1 122.9	1 459.9
Regulating services			
Carbon storage	34.3	393.4	511.4
Agricultural support	1	11.5	15.0
Fisheries support (nursery function)	11.4	130.8	170.0
Flow regulation	29.5	338.8	338.8
Sediment retention	3.1	35.2	45.8
Water quality amelioration	7.8	89.1	115.8
Sub-total	87.1	998.8	1 196.8
Cultural services			
Amenity value to property owners	1 586.8	18 200.0	23 660.0
Tourism value	2 400.0	27 527.8	35 786.1
Sub-total	3 986.8	45 727.8	59 446.1
Total	4 171.8	47 849.5	62 102.8

Within the city, and overall, amenity value is by far the most important value of natural and semi-natural open space. This large value is derived from a small proportion of the D'MOSS. The patterns observed for property value (representing value to residents), and tourism value were similar, with certain areas in the EMA contributing significantly to both.

In contrast to amenity values, provisioning services are more prominent in the peri-urban and rural areas of the EMA. The substantial area of rural landscapes around the urban edge, much of which are communal lands under the ownership of the traditional authority, deliver important provisioning services to the large numbers of poor households residing in the relatively dense settlements in these areas. Within the urban edge, the large natural areas tend to be under private ownership or state protection. The value of these services is highest in the outer-west and southern extents of the municipality where there are still large tracts of natural vegetation, such as woodlands and forests. The provisioning value in the northern area of the EMA and in the urban core tends to be somewhat lower and largely restricted to the river systems and wetlands in these areas.

If urbanisation is properly managed, the spatial disjunct of provisioning and amenity values is likely to track the future growth of the city and lead to the increased value of the remaining open space areas. If not properly managed, a dead zone could be created at the city's periphery in terms of ecosystem services, and valuable opportunities will be lost. As Durban grows and the peri-urban areas become densely populated and urbanised, it is likely that the provisioning services from those landscapes will make way for amenity services to future urban inhabitants, as the demands of urban inhabitants replace those of the former rural inhabitants. Both within the planned urban edge and beyond, informal and rural settlements will continue to grow and densify, and the city will continue to be under pressure to provide housing for the poor for some time to come. It will be important to consider the implications of how this growth is allowed to happen. The findings of this study suggest that remnant green open space areas become increasingly valuable with urbanisation and increasing incomes. Thus ensuring the protection of key open space areas in the areas being settled would secure potentially valuable sources of amenity and spiritual and physical wellbeing for these future communities.

The role and spatial variation of regulating services is particularly interesting. Carbon storage is the most important of these services from a local economy perspective, and is also important from an international perspective. This value and the global value need to be taken into consideration in South Africa's and eThekwini Municipality's commitments to combating climate change. The value of agricultural support services is modest, due to the relatively small extent of activities that benefit from this service. These are also generally outside of the urban edge. The nursery service of estuaries, which supports the fisheries sector, is comparatively large. The fisheries that are supported include both recreational and small-scale commercial fisheries within and beyond the coastal areas of the EMA, though the majority of these beneficiaries are likely to reside within the EMA.

Three of the regulating services described are related to catchment hydrology. The capacity to perform these services tends to be greatest in the surrounding rural landscapes because of their location and size, but the beneficiaries of these services are downstream, and the value of hydrologic-related services is also dictated to a large extent by the location of infrastructure. Thus the spatial variation of these services was more irregular in relation to the urban edge than for provisioning and amenity services. The values of these services were found to be highest upstream of Inanda and Hazelmere Dams in the northern and outer-west areas of the EMA, where sediment retention and water quality amelioration were most valuable, and also in the catchments of the downtown and harbour areas, where flood attenuation was highly valuable. Within the lower urban areas, however, hydrologic-related services tend to have been overwhelmed to the extent that they can no longer ameliorate the increased run-off and pollution from urban areas to a significant extent. This is a general reality of urban systems which is increasingly being addressed through innovative engineering solutions. Indeed regulating services are one area where technological innovation does show promise of being able to augment or replace ecosystem services, and where increased efficiency may be also desirable to protect the supply of ecosystem services from aquatic ecosystems that, unlike terrestrial systems, are more certain to remain in place, in one form or another. The optimal balance between relying on the services provided by natural capital versus implementing engineering solutions to neutralise the effects of urbanisation on run-off and water quality is explored in more detail in a companion report (Turpie et al. 2016).

Although this was a desktop assessment which still has substantial room for improvement and refinement through further research, it represents the most comprehensive assessment of ecosystem services within an urban environment in Africa to date, and one of perhaps only a handful in the world. Overall, the study shows that the ecosystem services profile of an urban area is very different from that of non-urban landscapes or regional level assessments. While natural and semi-natural ecosystems within the study area provide a full suite of ecosystem services, the value is dominated by amenity services to residents and visitors, both of which make a considerable and tangible contribution to Durban's economy. Even so, the estimate of amenity value does not capture all of the recreational, spiritual and health benefits associated with of green open space, since estimating these values requires further data collection.

The findings of this study can be used to identify priority areas for supply of ecosystem services and will be useful for decision-making processes related to understanding the tradeoffs between spatial development and conservation. This is pertinent to both environmental and strategic development planning within the eThekwini Municipality in forming the development of a thriving, resilient city. While the study focuses on ecosystem services, it is important to note that it does not provide a full estimate of the value of biodiversity per se. Our study does not capture the existence value and some of the other intangible, cultural values attached to biodiversity, nor does it adequately capture the role of species richness and community structure on the capacity of ecosystems to supply ecosystem services. This is a shortcoming of most valuation studies, and it is for this reason that conservation and planning decisions cannot be made on the basis of economic values alone. Planning should also incorporate biodiversity targets that are determined on the basis of their intrinsic value and understood role in maintaining ecosystem integrity and resilience.

ACRONYMS AND ABBREVIATIONS

CBD	Central Business District
CCP	Cities for Climate Protection
CPI	Consumer Price Index
CPUE	Catch-per-unit-effort
CVM	Contingent Valuation Method
DAFF	Department of Agriculture, Forestry and Fisheries
DEARD	Department of Agriculture, Environmental Affairs and Rural Development
DLA	Department of Land Affairs
DWA	Department of Water Affairs
D'MOSS	Durban Metropolitan Open Space System
EDGE	Economic Development and Growth in eThekwini
EM	eThekwini Municipality
EMA	eThekwini Municipal Area
EESMP	eThekwini Environmental Services Management Plan
EMSCP	eThekwini Municipality Spatial Conservation Plan
EMD	Environmental Management Department
EPCPD	Environmental Planning and Climate Protection Department
GDP	Gross Domestic Product
GIS	Geographic Information System
HPM	Hedonic Pricing Method
ICLEI	International Council for Local Environmental Initiatives
IDP	Integrated Development Plan
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IPCC	Intergovernmental Panel on Climate Change
KZN	KwaZulu-Natal
LULC	Land Use Land Cover
MEA	Millennium Ecosystem Assessment
NPA	National Ports Authority
NTFP	Non Timber Forest Products
NTU	Nephelometric Turbidity Units
OLS	Ordinary Least Squares
SANBI	South African National Biodiversity Institute
SAT	South African Tourism
SDF	Spatial Development Plan
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Value
TIN	Total Inorganic Nitrogen
TLA	Total Living Area
TNC	The Nature Conservancy
TOC	Total Organic Carbon
TP	Total Phosphorous
TSS	Total Suspended Solids
WMA	Water Management Area
WRC	Water Resource Commission
WTTC	World Travel and Tourism Council
WTW	Water Treatment Works
WWTW	Waste Water Treatment Works

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I. INTRODUCTION

1.1 Rationale

It is increasingly appreciated that ecosystems can make a significant contribution to human welfare through the provision of raw materials and food, functions that influence air and water quality, climate, hydrology and the abundance of useful and harmful organisms, and the provision of opportunities for recreation and entertainment, spiritual fulfilment, cultural, educational and scientific activities (Barbier 1994, 2011, MEA 2003). While these ecosystem services are mostly associated with natural systems outside of cities, including the services provided to cities such as water quality amelioration, they can also be provided by the natural systems occurring within urban areas. In fact, urban ecosystems provide important amenities and contribute to the livelihoods and wellbeing of large numbers of people, and ultimately to the resilience of cities. However, especially in developing countries, natural urban open space areas are rapidly becoming degraded and lost as a result of high rates of urbanisation and a lack of city finances to retain and manage them.

Various types of environmental assets exist within cities, which yield a range of benefits, or ecosystem services, to different sectors of society (Figure 1.1). However, there is generally a paucity of understanding of both the ecological functioning and the value of the existing natural capital in African cities in particular, or of the trade-offs involved in developments that replace or degrade these assets.

African cities are faced with the rapid influx of rural poor seeking better opportunities in addition to the intrinsic growth of the cities' populations. Because this rate of growth often outpaces plans and the capacity of city managers to provide the necessary services, it results in the development of informal settlements and results in a burgeoning poor population and attendant social problems. This puts major financial pressures on cities which are faced with provision of housing and services. One response is to plan urban economic development that will create employment opportunities. It is generally

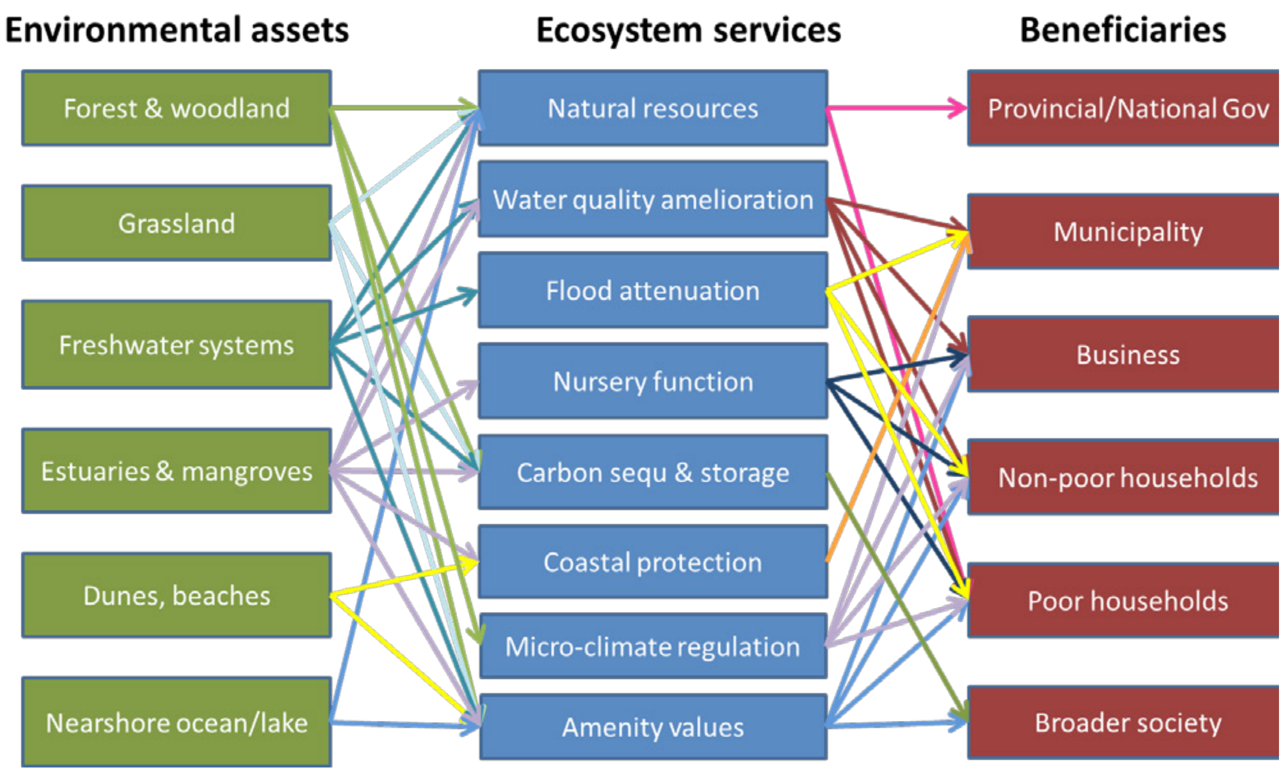

Figure 1.1 Relationships between urban natural assets, ecosystem services and their beneficiaries
Source: Author

understood that economic development has to keep pace with the growing demand for jobs in order for these households to contribute financially to service provision and avoid a downward spiral, and developers are therefore encouraged to bring such opportunities. Thus the tandem growth of informal settlements and formal developments steadily contributes to the conversion of open space areas within and around cities. Added to this, the lag in service provision and overwhelmed capacity for municipal functions also leads to the pollution and degradation of the natural areas that remain.

These issues are as relevant to Durban as to any other African city. Unlike many other African cities, however, Durban is located within a global biodiversity hotspot, and still contains a wealth of biodiversity. Some of this is protected in nature reserves, but much of it is in private hands or in communal lands on the city's periphery. City managers are divided over the level of attention that should be given to preserving these remaining natural areas. While it is argued that they make a significant contribution to biodiversity conservation in the province (EPCPD 2012), provide valuable ecosystem services (Roberts *et al.* 1999) and will contribute to the city's resilience in the face of climate change (Cartwright *et al.* 2013), the counter argument is that much of this area should make way for much needed development to relieve the escalating problem of unemployment. In the meantime, managers of these natural areas have to make do with a very small percentage of the city's budget, reflecting the current priorities of the city.

It is commonly argued that these issues arise because people do not understand the value of ecosystems, or of green open space areas[1] in cities (TEEB 2010). Based on this premise, the value of Durban's Metropolitan Open Space System (D'MOSS) was estimated in 2001 (eThekwini Municipality 2002), resulting in an estimate of some R3.1 billion per annum. This study indeed raised public sector awareness of the value of these areas, and resulted in improved allocation of resources for their management (Mander, pers. comm.). However, the effect of such a valuation can have a limited political lifespan (Roberts 2008), particularly if it is presented as a single large number. In reality, many decisions are made at the margin. Therefore, part of the reason for the limited usefulness of this study was the poor spatial resolution of its estimates, which were extrapolated from international studies (mainly Costanza *et al.* 1997) on the basis of total areas of different habitat types within the city. More localised and locally-based estimates of value are required in order to understand the current value of different open space areas and the resources that should be allocated to their protection and management. Understanding the relative value of different open space areas will also provide a better understanding of the potential opportunity costs of developing these areas. They can help to evaluate conservation-development trade-offs within urban areas and also to evaluate the potential trade-off between allowing the loss of open space within the urban edge, versus loss of natural areas through planned urban expansion or unplanned urban sprawl (Elmqvist *et al.* 2013). Furthermore, it is often extremely difficult and expensive to restore or rehabilitate ecosystems once they have been degraded past a certain point. Investing in the maintenance and protection of natural capital is therefore important and will translate into future cost savings and improved human well-being. For these reasons there is a real need for cities to factor ecosystems and the services they provide into urban planning, management, budgets and policies (TEEB 2010).

The study of ecosystem services and their value to society has made significant advances since the 1990s. This has been partly due to the advent of vastly improved spatial data which allows a better understanding of geographic variation in the supply of and demand for ecosystem services. Nearly all of the research effort has taken place outside of urban areas, where ecosystems are large, but increasingly fragmented and threatened by rural land uses and a host of anthropogenic pressures. While some work has taken place on the impacts of urban sprawl on ecosystems at regional scales (e.g. Eigenbrod *et al.* 2011), relatively little work has been done on role and value of ecosystems within urban areas, and most of these have been limited to single types of services or value.

1.2 Aim of the study

The aim of this study was to provide estimates of the value of ecosystem services provided by natural open space areas within the eThekwini Municipal Area (EMA), and to map the geographic variation in these values as far as possible so as to be able to compare both areas and types of value, using available and locally-relevant data.

1.3 Ecosystem services valuation framework

1.3.1 Classification of ecosystem services

The concept of ecosystem goods and services stems from the perception of ecosystems as natural capital which contributes to economic production (Kareiva *et al.* 2011). Goods are the resources that are harvested such as wood and fish, services contribute to economic production or save costs such as waste assimilation, and attributes relate to the structure or organisation of biodiversity such as rarity, diversity and beauty. The Millennium Ecosystem Assessment (MEA 2003) defined ecosystem services as "the benefits people obtain from ecosystems" and categorised the services provided

[1] comprising a mix of natural and semi-natural areas, including man-made outdoor recreational areas

by ecosystems into provisioning services, regulating services, cultural services and supporting services. Provisioning services relate to the living (e.g. fish and grass) and non-living (e.g. water and sand) resources that are harvested for building materials, food and medicines, regulating services include climate regulation, waste treatment and water purification, cultural services include the aesthetic, spiritual, educational and recreational benefits derived from ecosystems, and supporting services include nutrient cycling, and services that maintain the conditions for life on Earth. The first three align well with the definitions of goods, services and attributes described above. Although changes in supporting services influence the delivery of provisioning, regulating and cultural services, they are usually ignored in valuation studies to avoid double counting. The main ecosystem services generated by natural or semi-natural systems are described in Table 1.1.

1.3.2 Total Economic Value framework

The Total Economic Value (TEV) of ecosystem services is comprised of different types of value which are categorised into direct use, indirect, option and non-use values (Figure 1.2).

Use values relate to the actual use of the good in question (e.g. a visit to a National Park), planned use (e.g. a visit planned in the future) or possible use. Actual and planned use are easily understood concepts, but possible use is more ambiguous (but not any less important) as it relates to what people would be willing to pay to maintain a good in existence in order to preserve the option of being able to use it in the future (Pearce *et al.* 2006). Non-use value refers to the willingness to pay to maintain a good in existence even though there is no actual, planned or possible use. Theoretically, TEV is the sum of all use and non-use values, although depending on how they are measured they may not be additive. When adding values it is important to make sure that double-counting does not occur. Use and non-use value can be classified further and these values are explained below.

Table 1.1 The main ecosystem goods and services generated by natural or semi-natural systems

Ecological characteristics	Economic characteristics	Types of Services	
Stocks of resources	Goods	Provisioning	Fishery resources Sand Grazing Fuelwood Woody raw materials (e.g. timber, poles) Non-woody raw materials (e.g. thatching grass) Food and medicinal plants Animals and birds (hunting)
Ecological functions and processes	Services	Regulating	Carbon sequestration and storage Regulation of hydrological flows (infiltration, flood attenuation) Amelioration of water quality (detoxifying pollution, dilution & transport of pollution) Erosion control and sediment trapping Habitat for organisms useful in pollinating and controlling pests of croplands Refugia/critical habitat for organisms used consumptively or non-consumptively beyond the study area
Ecosystem characteristics and biodiversity composition	Attributes (aesthetic, biodiversity, rarity, physical features)	Cultural	Cultural activities and heritage Recreational use and enjoyment Scientific and educational value Spiritual and religious activities and well-being

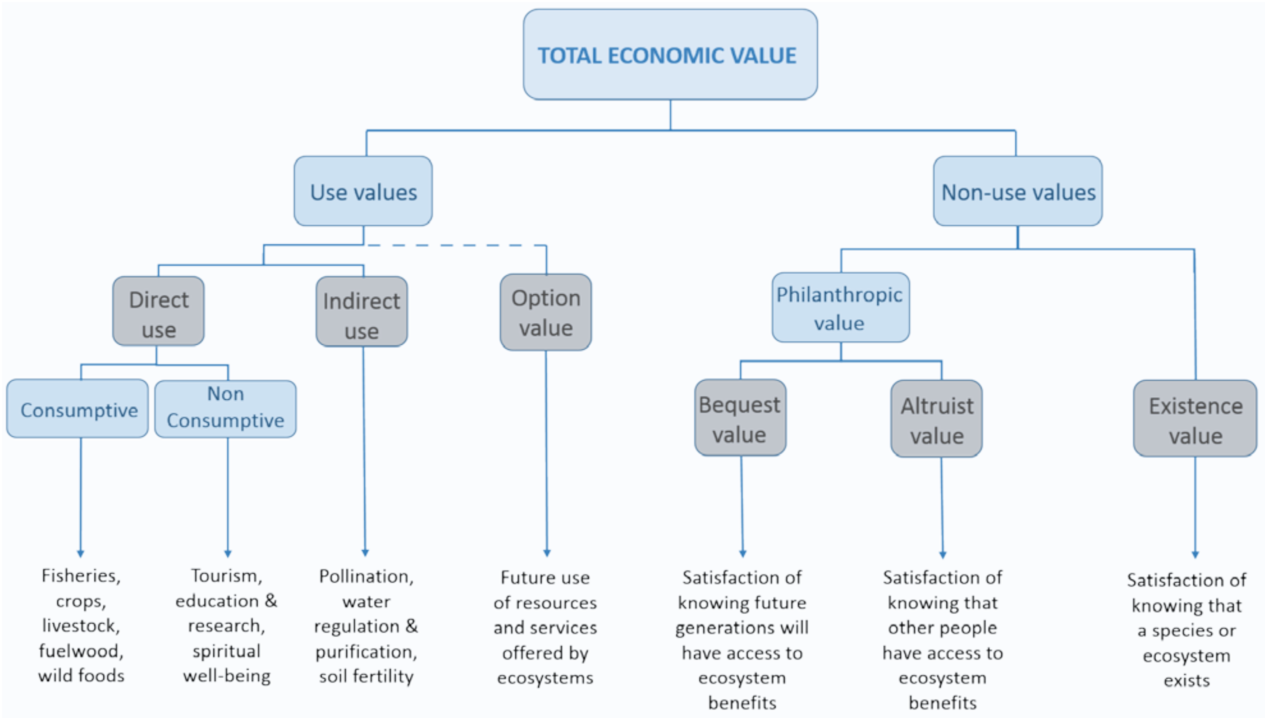

Figure 1.2 The classification of ecosystem values that make up Total Economic Value (TEV)
Source: TEEB 2010

Consumptive use values are based on the provision of ecosystem goods such as crop production, fisheries, livestock grazing, wild plant harvesting and hunting. Non-consumptive use values are based on ecosystem attributes and include tourism, recreational activities, research and study opportunities, and aesthetic, spiritual and religious appreciation or use of ecosystems.

Indirect use values are derived from the regulation services provided by species and ecosystems. Ecosystem functions may either generate outputs that form inputs in production processes elsewhere (i.e. the benefits are realised off-site), or they result in engineering cost savings by performing functions that would otherwise require costly infrastructure or man-made processes. These services include air quality regulation, water purification, erosion control and pollination. Their value is usually understood to be positively related to the level of ecosystem health or integrity, and are seen as a public service which are generally not reflected in market transactions.

Option value relates to the importance that people give to the future availability of ecosystem services for personal benefit (TEEB 2010). These include possible medicinal, leisure, agricultural and industrial uses. Option value is particularly important when there is uncertainty regarding the potential use and value of the ecosystem in the future (Perman *et al.* 2011). Although the ecosystem may be underutilised at present, it could prove to be valuable for tourism, research or other commercial enterprises in the future. Option value may also be important for local communities that have uncertain incomes and will rely on natural resource harvesting in future times of need. While option value cannot be measured, it is possible to estimate a 'quasi-option value', which is society's willingness to pay to retain the option for future use of the ecosystem (Perman *et al.* 2011).

Non-use values from ecosystems are the values that do not include any direct or indirect uses of ecosystem services. They reflect the satisfaction that individuals derive from knowing that ecosystem services are conserved and that other people have or will have access to them (TEEB 2010, Kolstad 2011). These may arise from personal values or intergenerational equity concerns. Estimating non-use values is far more difficult than estimating use values, mostly because non-use values relate to moral, aesthetic, charitable or religious properties for which there are usually no markets (TEEB 2010, Kolstad 2011). Nevertheless, non-use values are reflected to some extent in society's willingness to pay to protect resources and ecosystems, and with appropriate market mechanisms can be captured through transfers and converted to income.

Table 1.2 provides an overview of the linkages between the TEV framework and the supply of ecosystem goods, services and attributes. The TEV framework aligns directly to the goods, services and attributes framework and the Millennium Assessment (2003) concept of ecosystem services. Supporting services are valued through the other categories of ecosystem services.

Table 1.2 The linkages between the TEV framework and the supply of ecosystem goods, services and attributes

Types of services		Direct use value	Indirect use value	Option value	Non-use values
Provisioning (Goods)	Fresh water supply, fisheries, wild foods, natural medicines, fuel, biochemicals	X	-	X	-
Regulating (Services)	Climate regulation, water purification, nutrient recycling, pollination, air quality regulation etc.	-	X	X	-
Cultural (Attributes)	Recreation & tourism, aesthetic values, cultural and religious heritage	X	-	X	X
Supporting	Primary production, soil formation, nutrient cycling	Supporting services are valued through the other categories of ecosystem services			

Much of the confusion and debate around categorising and assessing the value of ecosystem services revolves around the extent to which different services should be treated as intermediate versus final services, and the extent to which the ecosystem is responsible for the benefits described (Barbier *et al.* 2011). For example recreational benefits are derived from a combination of natural and man-made capital. These problems only really exist for static assessments of value such as those by Costanza *et al.* (1997, 2014). To some extent, this can be solved by focussing only on the final services in order to avoid double counting. However, since it is often the supporting or intermediate services that are affected by policy changes, it is far more relevant to assess changes in welfare that will result from a change in the state of natural capital. That way, the fact that values depend partly on man-made capital, such as hotels and boats, is not problematic to the analysis.

1.3.3 Economic value

The way in which values of ecosystem services are expressed also varies between studies. Different measures of value are relevant to different decision-makers. Individuals and firms make decisions on the basis of their own financial and/or utility gains. Governments make decisions on the basis of overall welfare gains (including contribution to income and employment as measured in the national accounts). At a more local level, municipalities may make decisions based on the generation of revenues, e.g. from property rates. It is important to understand value from both an individual/firm perspective and a government or social planner perspective, since the former constitute the market forces of change, and the latter are required to make decisions that are in the overall interest of society. In this study, we take a social planner's perspective as far as possible, but also highlight financial implications for the municipality.

Economic value of the environment can be defined as the value of an asset, which lies in its role in achieving human goals, be it through aesthetic pleasure, the production of marketed commodities or spiritual fulfilment (Barbier *et al.* 2009, TEEB 2010). Value is recognised as a person's willingness to pay for the services that flow from an asset and this willingness depends on the socio-economic context in which valuation takes place, such as human preferences, the distribution of income and wealth, culture, production technologies and institutions (Barbier *et al.* 2009). A change in any of these variables ultimately affects the estimated economic value. In a market economy, money is a universally accepted measure of economic value, because the amount someone is willing to pay for an asset tells how much of all other goods and services they are willing to give up for that asset. Market prices, however, do not always accurately reflect economic value, since many people are actually willing to pay more than the market price.

Economic surplus or total economic welfare is measured as the total benefit that society derives from an economic transaction. Economic welfare is represented by 'consumer surplus' and 'producer surplus' (Figure 1.3). Consumer surplus is calculated as the difference between an individual's willingness to pay for a product or service and the actual amount paid. For society as a whole this is measured as the area below the demand curve for a good and above the price of that good. The value of the good changes if the price or quality of the good changes, or if demand for the good changes as a result of changes in price and quality of substitute or complementary goods. Similarly, producer surplus is the additional benefit that producers gain, in terms of profit, when the price they receive for a good is more than the minimum that they would be prepared to supply it for. This is measured as the area above the supply curve and below the market price (Figure 1.3). Therefore, the total net economic benefit or costs of a change in an ecosystem is the sum of consumer and producer surplus, less any costs associated with the policy or initiative.

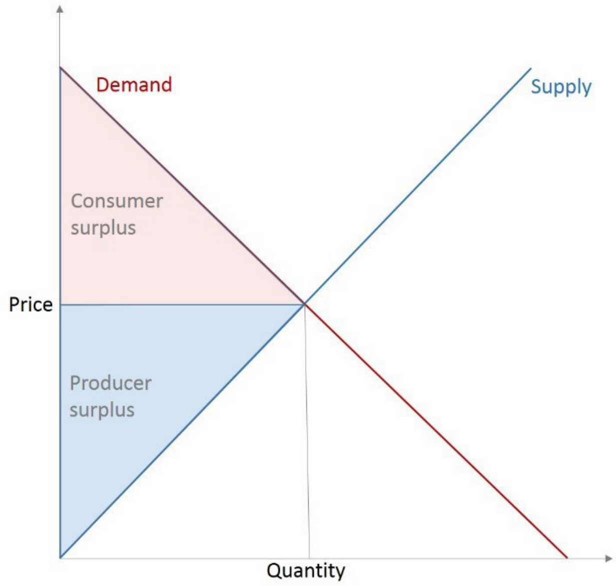

Figure 1.3 Demand and supply curves for a good, showing the calculation of consumer and producer surplus

Market values usually exist for services such as timber, fuelwood and carbon sequestration/storage. Where markets are absent, estimates have to be obtained indirectly. This can be done by looking at related markets. For example, land which is more fertile will trade at a higher price, the differential reflecting the value of soil fertility. Alternatively, unpriced services can be valued by estimating how much it would cost to replace them, or the damages that might be incurred if they were removed.

1.3.4 Present value

This study focuses on the values of natural systems within eThekwini municipality. Depending on the approach used, some values are estimated as capital values, such as the capital costs required to use an engineering design to replace the supply of a service, and others as annual flows of value, such as the annual value of fuelwood production. In order to estimate the asset (capital) value of these natural systems (natural capital), it is necessary to consider the value of all the benefits generated over time. This is the present value, which is the discounted sum of the flow of benefits generated. Estimating the present value of each service requires deciding on a time frame for the analysis and a rate of discount. Discounting of the flow of values gives greater weight to present value than to future values. It is used to estimate the amount of money one would have to have now in order to reach the value generated in each future time period if it was subject to compound growth. The choice of discount rate is controversial, since higher discount rates reduce future values more and therefore reduce overall present values. From an investment perspective, it makes sense to choose a discount rate that reflects the rate of return on capital. However, this does not necessarily reflect the social rate of time preference, and it is often argued that environmental valuation should employ lower or declining discount rates that better reflect intergenerational preferences. In this study, we have followed the World Bank guidelines in applying a discount rate of 6%. Given the World Bank's investment perspective, this certainly leads to an underestimate of the value of ecosystem services to society. In the USA, the Environmental Protection Agency recommends using a social discount rate of 2 – 3%, and in the UK, rates of 2.4 – 3.5% have been suggested (Perman *et al.* 2011). A range of estimates of present value are therefore provided using discount rates of 6% and 3%.

1.4 Overall approach and limitations

This study was carried out as a desktop study based on available data. Modelling assumptions were based on data from within the study area, drawing on the regional, national or international literature only where necessary. The study focused on the direct values associated with the provision of natural resources, indirect use values associated with regulating services and ecosystem functioning, and the amenity values generated by ecosystem attributes. Estimation of option values and non-use values associated with ecosystems require survey-based methods and were thus beyond the scope of this study.

The values of different types of provisioning, regulating and cultural services were estimated based on consideration of demand and supply as appropriate, and in the case of provisioning services, based on estimated sustainable yields. Because of the broad scope of the study, a wide variety of methods has been employed to tackle the various types of ecosystem services, and includes both well established and relatively novel approaches. These methods are described in detail in the relevant chapters of the report.

The annual flows of value were expressed in terms as close to net economic value as possible. Because the latter is the sum of producer and consumer surplus, and estimating consumer surplus requires stated-preference surveys, the estimates generally provide a conservative estimate of the welfare gains from natural capital. Annual flows were then used to estimate the value of natural capital as a net present value.

Attempting to put a value on natural capital has some inherent limitations that are still being grappled with in the field of natural resource accounting (www.wavespartnership.org [2]). The values of ecosystem services are not simply measureable as final values as in the national accounts. Most ecosystem services act as inputs into various forms of economic production, the outputs of which would not accrue without a range of inputs including man-made capital. For example, tourism value might be realised as a result of infrastructure and tourism facilities as well as biodiversity attractions. In these case, the values yielded by ecosystems are difficult to isolate as an asset value. To get around this, our approach has been to try and determine what would be lost if the natural asset (or its relevant function) was lost altogether. In reality, these are not usually all-or-nothing situations, as natural capital may be degraded or diminished rather than lost. Nevertheless, this study can provide the platform from which studies of marginal change under a range of scenarios will become possible.

Some other caveats need to be borne in mind in interpreting the results of this study. Firstly, South Africa, irrespective of its value, has an obligation to a certain level of biodiversity protection as a signatory of the Biodiversity Convention, and areas within the eThekwini Metropolitan Municipality may be critical to meeting this mandate. Secondly, while we can assess current value, it is difficult to assess the future role and value of ecosystems in a rapidly changing world. Natural systems are likely to provide an important buffer to the impacts of climate change, and will enhance the resilience of cities. These relationships are not well understood because of the uncertainties involved, and therefore trade-offs should be made with a large margin as a precautionary measure.

1.5 Structure of the report

The following two chapters provide some context. Chapter 2 provides an overview of the eThekwini Municipal Area (EMA), including location, geography, administration and land tenure, population and economy, and a brief description of the natural systems and biodiversity of the study area, most of which is counted as part of the D'MOSS. Chapter 3 provides an overview of ecosystem services, their classification and their values. The next three chapters focus on provisioning, regulating and cultural services, respectively. These chapters are divided into individual services falling under each category. Chapter 4 estimates the provisioning value, within sustainable limits, of natural areas that are used for the extraction of water, sand, plants, wild meat and fish. Chapter 5 estimates the value of natural systems in terms of their contribution to flood attenuation, water quality amelioration, carbon storage, and support functions for agriculture and marine fisheries. Chapter 6 focuses on the amenity value of natural and semi-natural systems, in terms of the impact that this as on property values and domestic and foreign tourism expenditure. Chapter 7 draws together the findings and discusses their overall implications.

[2] The Wealth Accounting and the Valuation of Ecosystem Services (WAVES) partnership, led by the World Bank, aims to promote sustainable development by incorporating natural resources into development planning and national economic accounts.

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II. OVERVIEW OF THE ETHEKWINI MUNICIPAL AREA (EMA)

2.1 Geography and climate

The city of Durban is located in the eThekwini Municipal Area (EMA) in the province of KwaZulu-Natal, South Africa and contains the largest port on the east coast of Africa (Figure 2.1). The EMA covers an area of approximately 2297 km2 extending from the Tongati River in the north to the aMahlongwa River in the south. The eastern edge of the EMA is bounded by 98 km of Indian Ocean coastline and to the west the boundary extends inland to 50 km at its widest point at Cato Ridge. The EMA is bordered by three other district municipalities; iLembe to the north, uGu to the south and uMgungundlovu to the west.

The topography is generally rugged across the EMA, especially inland in the valleys of the uMngeni River catchment near to the Inanda Dam (EPCPD 2012). There are some flatter areas towards the coast which include the old alluvial coastal plain that extends from just north of the uMngeni Estuary through the Durban city centre to just south of the Mbokodweni Estuary (IDP 2014). The rugged interior is interspersed with flat sandstone tabletops which range in size from large expansive areas like in the Kloof, Waterfall and Hillcrest areas, to the smaller more isolated uplands like the Inanda, Matabatule and Fudu mountains (EPCPD 2012). The highest point in the EMA is 873 m near Bartlett Estate in Hammarsdale.

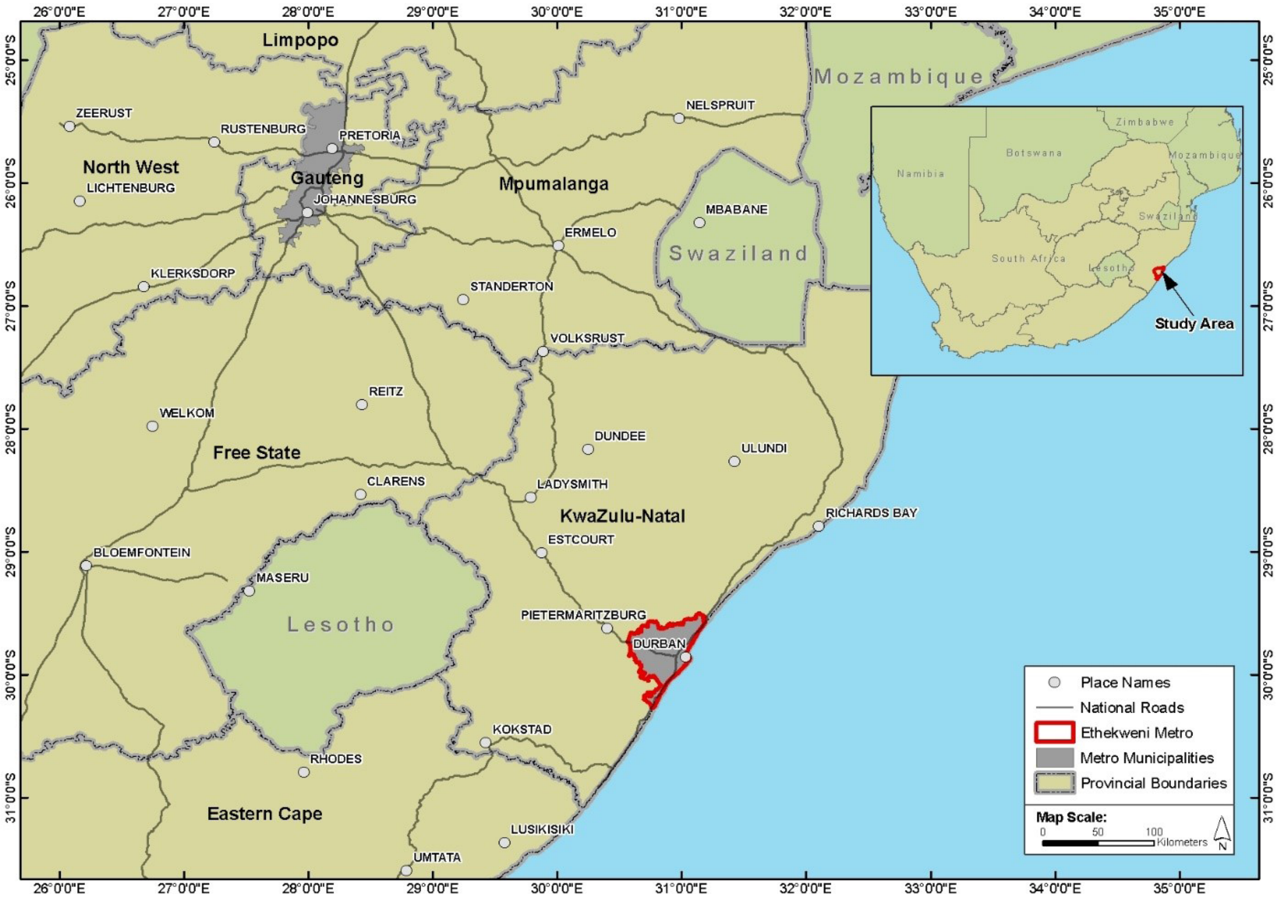

Figure 2.1 The eThekwini Municipal Area (EMA) is located on the east coast of South Africa and covers an area of 2297km^2

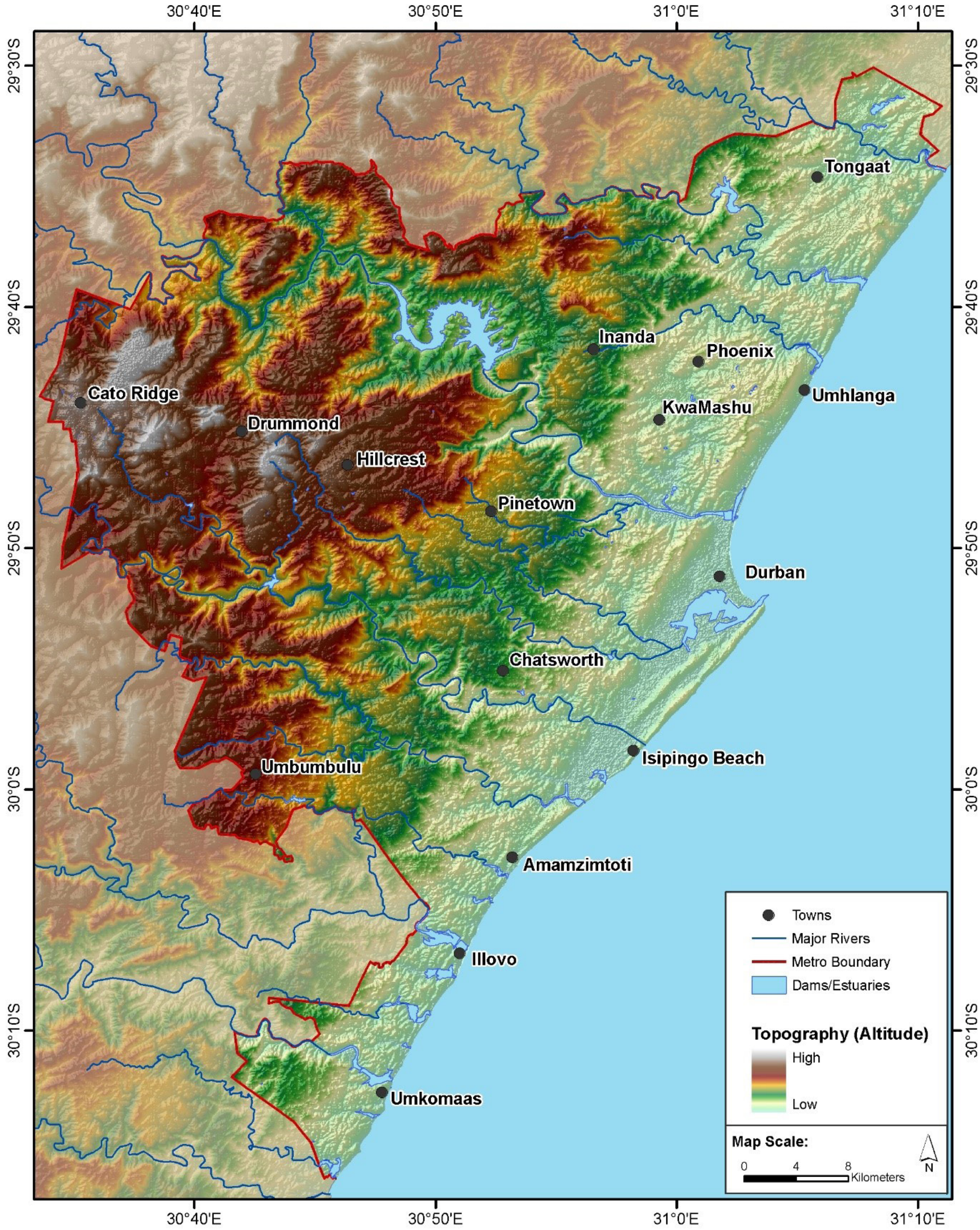

Figure 2.2 Topographical map of the eThekwini Municipal Area

The area has a subtropical climate with humid wet summers and mild dry winters (EPCPD 2012). The warm Agulhas Current that flows southwards along the coast has a moderating influence on the climate, keeping winter temperatures mild and summers warm and humid with a maximum average daily temperature of 28°C (Roberts & O'Donoghue 2013). The rainy season falls between September and March with a mean annual precipitation of over 1000 millimetres (Roberts & O'Donoghue 2013). Temperatures are usually highest at the coast and get cooler as one moves inland. The change in temperature between seasons is greatest in the higher altitude areas in the west. Rainfall tends to be highest in the south of the EMA and along the coast but rainfall seasonality is greatest in the west, with most of the rainfall falling within the summer months. The predominant winds blow parallel to the coastline in a north-easterly and south-westerly direction.

2.2 Land use and socio-economic context

The eThekwini Metropolitan Municipality is one of six metropolitan municipalities in South Africa and has the third largest population, after Johannesburg and Cape Town (StatsSA 2011a). The total population of the EMA is approximately 3.44 million, which is just over one third of the population of KwaZulu-Natal (StatsSA 2011a) and has been projected to rise to approximately four million by 2020 (IDP 2014). The majority of the population in the EMA are African (74%), followed by Indian (17%), white (7%) and coloured (2%; SDF 2014). As well as the urban area of Durban, the EMA also encompasses significant areas under peri-urban and rural land uses (EPCPD 2012). Approximately 45% of the EMA is considered rural, 30% is peri-urban and only 25% is urban (SDF 2014). This pattern is reflected in the population distribution (Figure 2.3).

Although only covering 2.5% of the area of the province EPCPD 2012), the EMA accounts for 65.5% of KwaZulu-Natal's and 10.7% of national GDP (IDP 2014). Key economic activities include wholesale and retail, manufacturing, trade, transport, storage and communication, financial business services and community services (IDP 2014).

There are approximately 945 910 households in the EMA with an average household size of 3.2 (eThekwini Municipality 2014a, SDF 2014). Of these, 55% are in formal dwellings, 34% in informal dwellings and 11% in traditional or rural dwellings (eThekwini Municipality 2014a). The unemployment rate in the EMA was reported to have decreased from 31.4% in 2006 to 20.4% in 2011, lower than the national average (StatsSA 2011a).

The extension of services to the outlying peri-urban and rural areas has improved significantly over recent years, with more households gaining access to services such as running water and electricity. Potable water (within 200 m from dwellings) is available to 92% of the EMA's population, electricity to 71% and basic sanitation (above the minimum service level) is available to 80% of the population (eThekwini Municipality 2014a). However, flush toilets connected to the sewerage mains or to septic tanks are available to only 50% of the city's population. In 2012 the percentage of people living under conditions associated with poverty was still significant at 32.3% (IDP 2014). As a result, almost all river systems and accessible natural areas have been impacted by some form of anthropogenic pressure (EPCPD 2012).

The rural areas of the EMA occupy approximately 1500 km2 of land in the surrounding areas of the southern and western regions, and include the peri-urban areas alongside the N2 and N3 corridors (SDF 2014). These rural areas generally have rugged and hilly terrain and dispersed settlement patterns with most of the population living in traditional dwellings on communal land holdings. A significant portion of the rural land in the southern and western regions is under the ownership of the Ingonyama Trust. The Ingonyama Trust is a corporate entity that was established in 1994 to administer the 2.8 million hectares of traditionally-owned land in KwaZulu-Natal for the benefit and welfare of the members of the tribes and communities living on the land.

The rural and traditional authority areas are largely characterised by severe poverty and unemployment with many of the households reliant on social grants and surrounding natural resources (SDF 2014). The heavy reliance on the natural resource base in these areas has resulted in environmental vulnerability which is further aggravated by fragmented service delivery, unresolved land tenure and a history of poor planning (SDF 2014). Communities in these areas participate in some small-scale maize and sugarcane farming and also farm some vegetables and fruits such as bananas, mangos, citrus, amadumbes (a type of sweet potato) and ground nuts (Institute of Natural Resources 2004).

Approximately 29% of the land in the EMA has been designated for agricultural use, although not all of this land is used for agricultural purposes (EPCPD 2012). Subsistence farming activities are found largely in the traditional authority areas and formal agriculture is dominated by sugarcane farming, especially in the northern and western areas (SDF 2014). Other formal agriculture includes timber, dairy, beef, piggeries, broilers, layers, sheep and goats, aquaculture, vegetables, fruit and cut flowers (Institute of Natural Resources 2004).

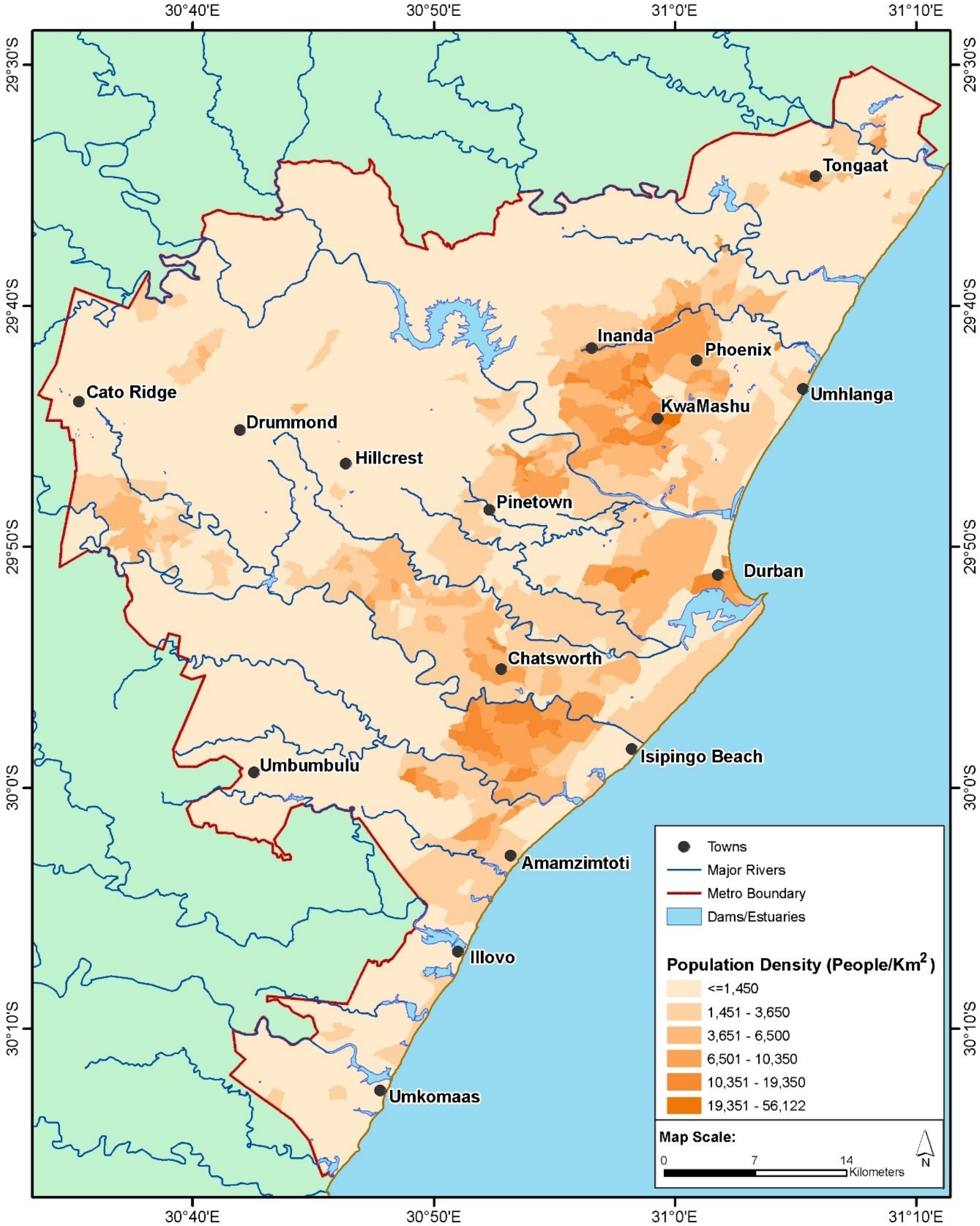

Figure 2.3 Population density (people/km²) for the eThekwini Municipal Area

2.3 Biodiversity and D'MOSS

The EMA is situated in the centre of one of 34 Global Biodiversity Hotspots, the Maputaland-Pondoland-Albany region (EPCPD 2012). This region contains more than 7000 vascular plant species, 25% of which are endemic to the area (EPCPD 2012). The fact that the EMA is located in a transitional zone between warm tropical and cooler temperate features as well as its topographical and habitat diversity means that it supports relatively high levels of biodiversity within this region (EPCPD 2012). The EMA contains three of the country's eight terrestrial biomes (savanna, forest and grassland), eight nationally recognised vegetation types (eastern valley bushveld, KwaZulu-Natal coastal belt, KwaZulu-Natal hinterland thornveld, KwaZulu-Natal sandstone sourveld, Ngongoni veld, scarp forest, northern coastal forest and mangrove forest), 4000 km of rivers, 98 km of coastline, 18 major river catchments and 16 estuaries.

These natural assets fall within the EMA's open space system, which also includes agriculture, man-made parks and sports areas. Known as the Durban Metropolitan Open Space System, or D'MOSS, this system of green open spaces covers 75 000 ha, or almost a third of the total municipal area, above the high tide mark (Figure 2.4; eThekwini Municipality 2012). The D'MOSS system incorporates areas of high biodiversity value that are linked together in a viable network (eThekwini Municipality 2012). These include nature reserves such as Paradise Valley and Burman Bush, large rural landscapes in the upper catchment areas, riverine and coastal corridors and some privately-owned land (eThekwini Municipality 2012). A significant proportion of D'MOSS land is located within the traditional authority areas in the outer-west and southern planning regions.

The EMA's natural open space areas can be categorised into terrestrial, freshwater, estuarine and marine ecosystems. These are distinguishable in terms of the flora and fauna that are found in and around them and the ecosystem goods and services that they provide (EPCPD 2012). These natural and semi-natural areas, found largely on the periphery of the EMA away from the city centre, provide a wide range of ecosystem goods and services across the whole study area. These ecosystem services provide resilience and can help to buffer the impacts of climate change and other pressing issues. The key environmental issues and a detailed description of the EMA's ecosystem characteristics are outlined below in more detail.

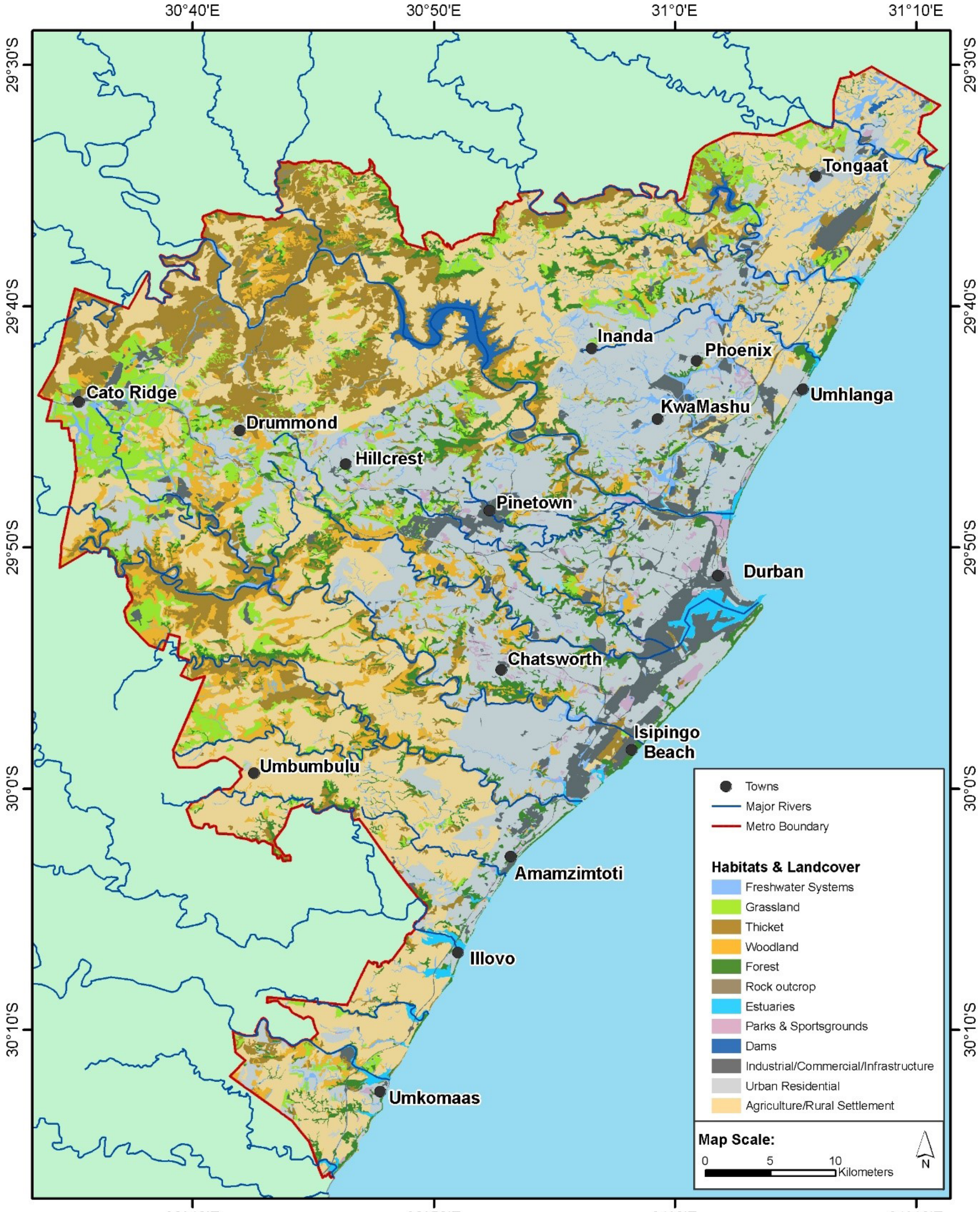

Figure 2.4 Habitats and land cover in the EMA. Freshwater systems, grassland, thicket, woodland, forest, rocky outcrops, estuaries, and dams are all part of D'MOSS

The terrestrial landscape in the EMA is essentially a mosaic of open grassland, woodland, thicket, thornveld and forest (EPCPD 2012). Almost all of the vegetation types in the EMA have been significantly transformed, are threatened and in need of protection, with several being critically endangered. Most (60%) of Dry and Moist Ngongoni Veld (endangered and critically endangered in KwaZulu-Natal, respectively) and almost all (99%) of the near-threatened Eastern Valley Bushveld is in the traditional authority areas, the latter occurring in deeply incised river valleys. The vulnerable KwaZulu-Natal Hinterland Thornveld, dominated by Acacia trees, usually lies between these vegetation types. None of these is in formally protected areas, but a lot of this is relatively well protected from transformation by the nature of the terrain (EPCPD 2012). Scarp forest which occurs in steep gorges and scarps is also fairly protected by the terrain, although it is heavily exploited for resources such as medicinal plants and building materials. 6% of this is in protected areas. More than two thirds of the critically endangered KwaZulu-Natal Sandstone Sourveld has been transformed, and only 1% is formally protected, in Krantzkloof Nature Reserve. The remainder of this vegetation, which is rich in forbs and has high levels of endemism, is under threat from fire and alien invasive plants. Coastal Belt grassland and bushveld vegetation occurs along the coastal plain up to 660 m altitude, and all four types are highly transformed and threatened, with less than 1% in protected areas. Coastal Forests have also become highly fragmented as a result of development. Most of the remaining forests are in formal planning scheme areas, and about 1% is protected. Small patches of Swamp Forest and Mangrove Forests also occur in the study area, with 72% of the remaining mangroves being protected in the Beachwood Mangroves Nature Reserve (EPCPD 2012). The health of all the terrestrial ecosystems has been assessed in terms of broad categories.

There is high plant diversity within these habitats, with a total of 2267 species recorded from 204 different plant families (EPCPD 2012). This represents more than half the known families found in South Africa. Endemicity is also high in the EMA with 379 species, 16% of the total, being classified as South African endemics (EPCPD 2012). There are also 82 mammal species in the EMA, including several threatened species, 69 reptiles, 27 amphibians and 526 bird species (EPCPD 2012). The populations of many of these species in the EMA are inevitably threatened by urbanisation and the activities and impacts that come with it.

The EMA also has a vast network of rivers and wetlands that drain into 16 estuaries along its coastline (Figure 2.5). Many of the original wetlands have been lost due to urbanisation. The remaining wetlands are mainly valley bottom wetlands and floodplain wetlands associated with the larger rivers (eThekwini Municipality 2011). The main river systems are the uMkhomazi, uMngeni, uMdloti, oHlanga, uTongathi, uMlazi, Mbokodweni and iLovu. The larger river systems originate in the Drakensberg Mountains, the medium rivers in the KwaZulu-Natal Midlands and the smaller rivers close to the coast (DWA 2013a) The health of the river systems has been well studied (Ground Truth 2006) and continues to be monitored. Most rivers are under increasing threat from impacts such as flow modification, sand mining and pollution from industrial and sewage effluent. Unplanned and extensive informal settlement development in the upper catchment areas is also having a large impact on these systems.

There are a 16 estuaries found within the study area (Figure 2.5). These range from small and temporarily closed estuaries with poor floral and faunal diversity, to large permanently open systems with very diverse faunal and floral communities. More than half of the estuaries found in the study area are highly degraded or in a poor state of health. The biggest threats include habitat loss, organic and chemical pollution from WWTW, informal settlements and industrial activities, unregulated sand mining, overexploitation, and upstream freshwater diversions or abstractions.

Outside of D'MOSS, the EMA coastline and marine ecosystem includes the sandy beaches, rocky shores and in-shore marine environment. The coastline and marine environment plays an important role in tourism and recreation activities and is also productive in terms of fisheries. While most of the KwaZulu-Natal coast is a high energy environment, Durban central beaches are relatively sheltered.

Appendix 1 provides a more detailed description of the biophysical characteristics of the terrestrial, freshwater, estuarine and marine ecosystems found within the study area that have a bearing on their value. In particular, this includes information about their health, extent, location, flora and fauna, and abundance of natural resources.

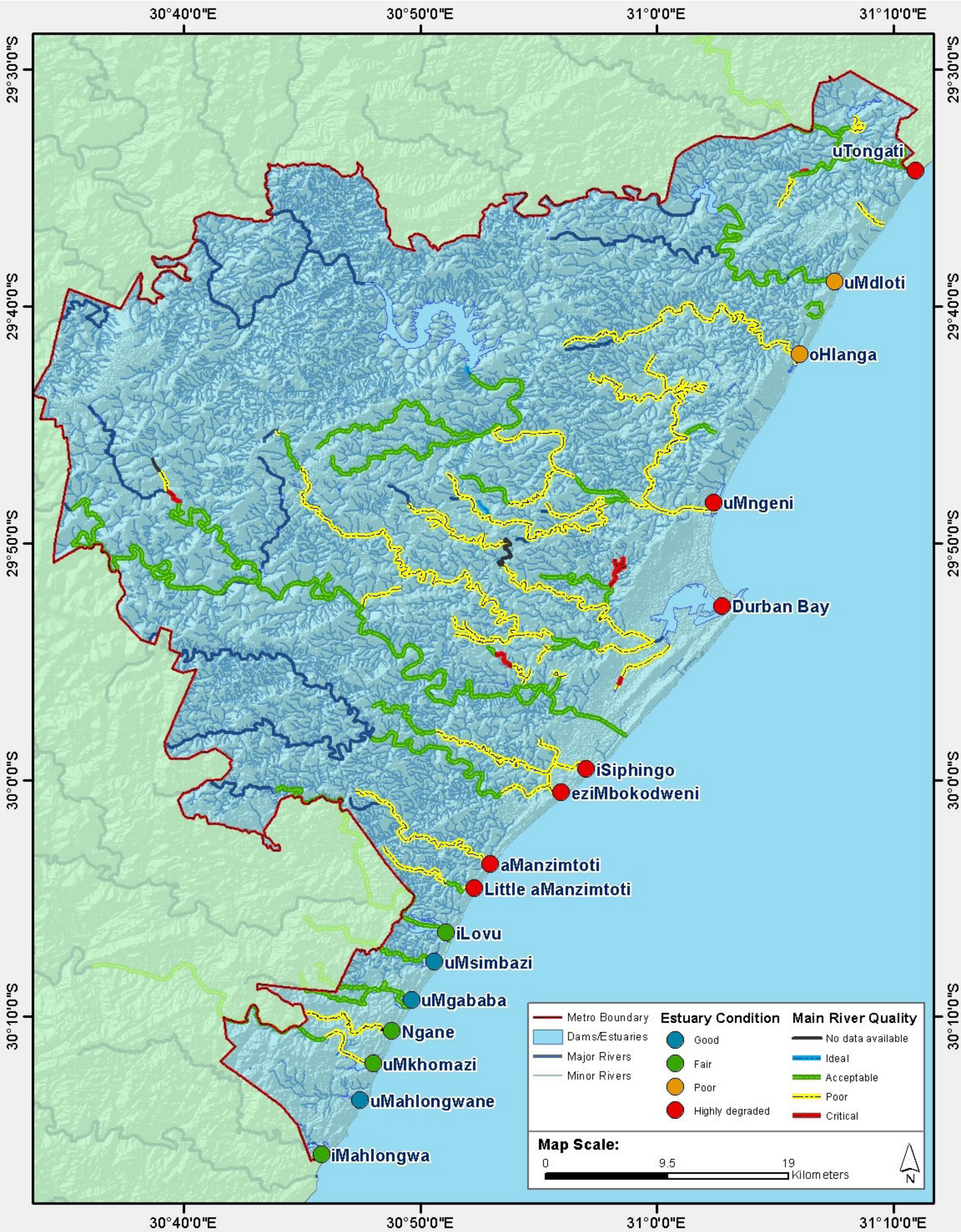

Figure 2.5 The major and minor rivers found within the EMA, and location of the 16 estuaries

III. PROVISION OF NATURAL RESOURCES

3.1 Introduction

The provisioning value provided by natural systems was estimated as the value of the sustainable yield of natural resources, as far as this is demanded. Terrestrial, freshwater and coastal ecosystems provide a number of living and non-living resources which are harvested for raw materials, food and medicine. In the eThekwini municipality these resources are predominantly harvested by poorer households on a subsistence basis or to generate some cash income. The greatest harvesting pressure comes from the rural communities that occupy the approximately 1500 km2 of rural areas in the hinterland of the EMA, where many people live in traditional dwellings within Ingonyama Trust lands, as well as the people living in poor peri-urban communities such as those that run alongside the N2 and N3 highways (SDF 2014), although markets for these resources will supply a much broader segment of the community, with some of the demand coming from both poor and relatively wealthy households within the urban area. The types of resources that are harvested in the EMA include water for domestic use, reeds and thatching grass, firewood, poles, food plants, bush meat and fish. This chapter estimates the provisioning value of natural habitats, taking factors influencing supply and demand into account as far as possible.

The use of natural resources has been studied to varying degrees in the province, particularly in the rural communal land areas under the Ingonyama Trust. However, few studies have been carried out within the EMA or other metros. Furthermore, while such studies can provide estimates of current use, this use is not necessarily sustainable. Snapshot estimates can therefore provide distorted estimates of value. Ideally, direct use value should be estimated based on a combination of expected demand and estimated sustainable yields. However, in some cases, the only available data are on actual harvests.

Available information on sustainable yields, market prices and input prices for different resource types were obtained from the literature, using locally-sourced information as far as possible (see Table 3.1). The vegetation types and condition of the natural areas, as assessed in detail by eThekwini municipality, was taken into account in estimating sustainable yields of the different resources. The estimated supply capacity of natural areas was then mapped in GIS. Urban typologies and characteristics of the urban populations were used to estimate the general level of demand, taking access constraints into account. In other words, no value was assigned to protected areas or areas that would not be accessible to potential users. A map of urban demand typologies (based on explicit assumptions outlined below) was superimposed onto the current supply capacity to determine the current provisioning value in terms of aggregate net income to households associated with specific habitats and land parcels within the study area.

Table 3.1 Summary of available information in the supply and demand of natural resource use in the eThekwini municipality

Natural Resource Harvesting	Available Information
Wild flora and fauna	• Peterson et al. (2012) developed a compendium of local wild-harvested species used in the informal trade in Cape Town, South Africa. • High & Shackleton (2000) estimated the value of wild and domestic plants in home gardens in a rural village in Bushbuckridge in the Lowveld of South Africa.
Natural Capital/ Ecosystem Services	• De Wit et al. (2009) looked at developing a financially motivated case for investing in natural capital in the city of Cape Town.
Natural resource use in wetlands	• Lannas & Turpie (2009) valued the provisioning services (hunting, livestock, water use, resource harvesting) of two wetlands, one in Lesotho and one in Cape Town. Information about hunting and harvesting rates (urban context)
Medicinal Plants and Grasses	• Mander (1998) conducted a comprehensive study of medicinal plant harvesting in KwaZulu-Natal providing supply and demand data. • Turpie et al. (2007) estimated the consequences of changing land use in Drakensberg grasslands. Value and sustainable harvesting rates estimated for medicinal plants and grasses.
Wild meat	• Kaschula & Shackleton (2009) estimated the quantity and value of wild meat offtake in a rural village in the Eastern Cape. • Grey-Ross et al. (2010) assessed the illegal hunting on farmland in KwaZulu-Natal, South Africa and the implications of this on the Oribi antelope.
Non-timber forest products (NTFP)	• Shackleton et al. (2002b) estimated the direct use values of non-timber forest products from three rural villages in the Kat River Valley. • Shackleton et al. (2007) estimated the direct use values of non-timber forest products from two villages on the Transkei Wild Coast. • Cocks & Wiersum (2003) documented the significance of plant diversity in rural livelihoods in the Eastern Cape looking at uses of NTFP's, amounts harvested and their value. • Shackleton & Shackleton (2004) reviewed the importance of NTFP's in rural livelihood security in South Africa. • Twine et al. (2003) estimated the direct-use values of savannah resources used by rural households in Limpopo, South Africa.

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Fuelwood and poles	• Glenday (2007) study on carbon storage and sequestration in eThekwini. Information used to estimate tree volumes and sustainable yields in specific D'MOSS habitats in the study area. • Shackleton (1993) estimated fuelwood harvesting and sustainable utilisation in communal land and in protected areas in the lowveld, South Africa. Information about fuelwood harvesting rates and sustainable yields. • Luoga et al. (2000) categorised different uses of resources and quantified the amount of wood used for firewood and building poles in miombo woodlands in eastern Tanzania. • Dovie et al. (2002) estimated direct use values of woodland resources consumed and traded in a rural village in South Africa. Information on fuelwood harvesting and prices. • Dovie et al. (2004) assessed the fuelwood crisis in Southern Africa by relating fuelwood use to livelihoods in a rural village. Information on fuelwood harvesting and prices. • Barnes et al. (2005) Forestry accounts from Namibia provide insight into calculating tree volumes and sustainable yield estimates.
Water use	• Turpie et al. (2010) assessed the aquatic ecosystem services of the Olifants, Inkomati and Usutu to Mhlatuze water management areas. Information about water use, water prices and the value of rivers. • GroundTruth (2006) conducted a study on the state of the rivers in eThekwini providing health status data.
Fisheries	• Dunlop & Mann (2012 and 2013) recent assessment of participation, catch and effort in the KwaZulu-Natal shore-based and offshore boat-based linefisheries. • Lamberth & Turpie (2003) assessed the role of estuaries in South African fisheries. Information on prices, values and estuaries by each region. • Forbes & Demetriades (2008) produced a report on Durban's estuaries providing information on health and fish of each system in the EMA.
Sand mining	• Demetriades (2007) investigated the location and size of sand mining operation on rivers and estuaries in eThekwini.CSIR (2008) assessed the quantities and values of sand supply from eThekwini rivers.

3.2 Approach

3.2.1 Sustainable yields

Data on sustainable yields for each resource and habitat type were obtained from the literature as far as possible. Where estimates of sustainable yields were not available, explicit assumptions were made based on estimates from comparable habitats. Average prices for each of the natural resources were obtained from the literature or based on expert opinion and inflated to 2015 prices.

The criteria and assumptions used to determine sustainable yields and values are described in more detail below. These were based on information collected from relevant studies carried out within the eThekwini Municipality and other areas within South Africa. Where data were not readily available for South Africa, studies from southern Africa and further afield were used.

3.2.2 Adjusting for habitat condition

The condition of terrestrial and freshwater habitats was taken from the eThekwini Municipality Spatial Conservation Plan (EMSCP; Figure 3.1, EPCPD 2012). D'MOSS parcels classed as being in a good condition (i.e. mostly natural with little or no degradation evident) were assumed to have the capacity to supply natural resources at 100% of the potential sustainable yield for that vegetation type and resource. Those classed as being of intermediate condition[1] were assumed to be able to supply resources at 50% of their potential. Parcels classed as degraded[2] were assumed to have lost the capacity to support sustainable natural resource harvesting.

For example, in the case of medicinal plants, woodlands and grasslands in a good condition have the ability to supply plant material sustainably due the size and distribution of this habitat in the EMA. Forests however have been over utilised in the EMA and their ability to supply material sustainably has been significantly impacted on. Usually production from forests would be greater than from woodlands and grasslands due to the variety of plant species found in forested habitats. However, their capacity to supply sustainable yields is far less than woodlands and grasslands due to most of the forested areas being overexploited and degraded in the EMA.

The size of each habitat patch was also considered to be an important factor in estimating the capacity to supply resources. Patch size and connectivity in urban environments has an important influence on biodiversity and ecosystem functioning, though this is also influenced by management within the remaining habitat patch and land-uses in the surrounding landscape (Wilson et al. 2009). Several studies have tried to determine the minimum patch size to support certain flora and fauna within urban environments (Wilson et al. 2009, Hennings & Soll 2010). Based on these studies, only patches greater than 12 ha were considered large enough to be able to support resource harvesting.

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1 < 50% of the area has low (5% - 33%) to moderate (34% - 66%) estimated levels of alien plant infestation and/or limited soil exposure (< 33% of area).

2 > 50% of the area has moderate (34% - 66%) to high (67% - 100%) estimated coverage of alien invasive plants and/or extensive soil erosion (> 33% of area)

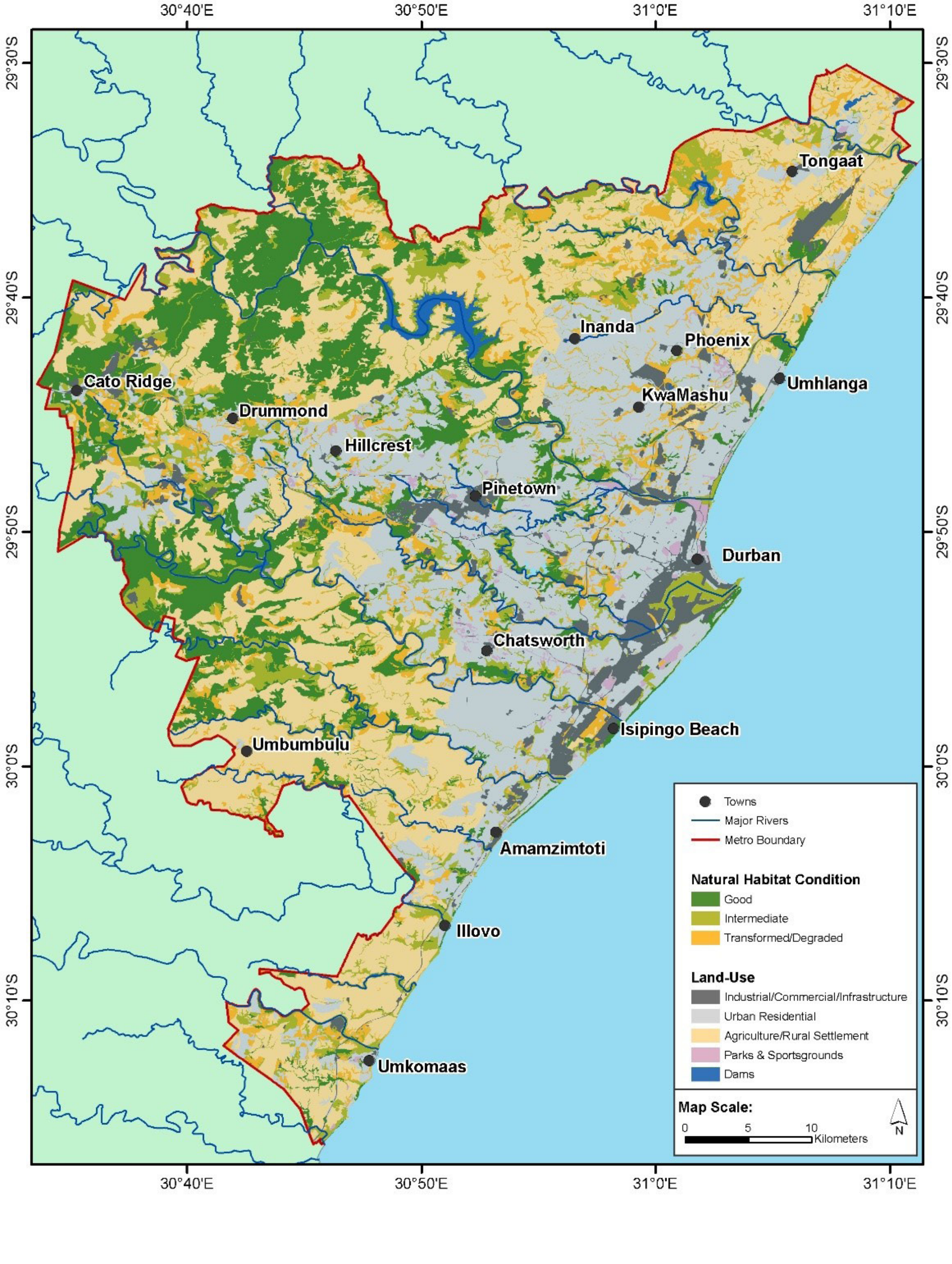

Figure 3.1 Habitat and land use map showing the condition of the natural habitat found within D'MOSS

Information relating to the condition and functioning of estuaries was taken from Forbes & Demetriades (2008; Table 3.2) and the National Estuary Biodiversity Assessment (van Niekerk & Turpie 2012). The condition, size and type of each estuary was linked to their capacity to supply natural resources. Small and/or degraded estuaries with poor water quality, severely impacted habitats and reduced or completely removed estuarine processes were assumed to lack the capacity to support natural resource harvesting. There are five estuaries (uTongathi, iSipingo, eziMbokodweni, Amanzimtoti and Little Amanzimtoti) that are highly degraded (Forbes & Demetriades 2008) and are known to have poor water quality and reduced fish abundance and diversity. Therefore it was assumed that the provisioning value for fishery resources in these estuaries was zero. The Ngane Estuary, recorded as being in a fair state, has low fish numbers and diversity as a result of its small size. The fishery resources value associated with this estuary was adjusted to be one third of its assigned value.

Table 3.2 Estuarine state ranking based on health and functionality used to assign condition to each estuary in the EMA (Source: Forbes & Demetriades 2008)

Estuarine State	Description
Excellent	Estuaries with high levels of habitat integrity, good water quality, high diversity and high provisioning levels of goods and services
Good	Estuaries with most of the core estuarine habitat and estuarine support habitats still present, good water quality, diversity of habitats and species, and estuarine processes in place
Fair	Estuaries with core estuarine habitat intact, some estuarine support habitats, impacted water quality and some loss of diversity and key estuarine process in place
Poor	Estuaries with impacted core estuarine habitat. Substantially reduced or no estuarine support habitats, polluted water, substantial loss of diversity and/or abundance and key estuarine processes impaired
Highly Degraded	Estuaries which have had major impacts on core estuarine habitats through infilling, canalisation and pollution, substantially reduced or no estuarine support habitats and major loss of key estuarine processes

3.2.3 Adjusting for expected demand

The demand for natural resources was assumed to be driven by the numbers of rural and poor households living within close proximity to natural areas. There are a significant number of rural settlements, peri-urban settlements and informal settlements spread widely across the EMA, all of which are in close proximity to natural open space areas and could be assumed to have a moderate to high demand for natural resources. Because these settlements were so widely spread and almost all natural space in the EMA was accessible, only land ownership was used to determine which natural areas could be harvested. All tribal authority land and all state undeveloped land not under formal protection was considered available for the harvesting of natural resources. A number of resources are known to be located on agricultural land and within protected areas. However farm land is privately owned land and the therefore the harvesting of resources from these lands and within protected areas is illegal. Therefore all land parcels that fall outside of tribal land and state undeveloped land were excluded from the analysis.

Remoteness was considered to be a harvesting constraint and therefore resources located on steep slopes were considered inaccessible and unlikely to be harvested due to their position in the landscape. Any natural vegetation located on slopes steeper than 50 degrees was considered inaccessible for resource harvesting.

3.3 Water

Rivers and streams are used as an important source of water for domestic purposes in rural, peri-urban and informal settlements, both in the home for drinking and bathing and also directly in the rivers themselves for the washing of clothes and as drinking water for livestock. Households tend to collect water in containers for household use but washing is usually done within the rivers and streams. Census data provided the most comprehensive estimate of the degree to which households in the EMA rely on rivers and streams as their main source of water. The reliance on rivers for domestic water use is low, with 91% of the EMA population receiving their water supply from municipal connections and a further 4% relying on water tanks and rain water collection tanks. Approximately 0.5% of households in the EMA rely solely on rivers and streams for their main source of water (StatsSA 2011b). Although the Census data provided information about the number of households relying on rivers and streams, the actual quantity of water collected from rivers in the EMA was not known and therefore an average of 25 litres/person/day, based on the basic human needs rule, was used. This is similar to the amount found in an empirical study in in the Olifants, Inkomati and Usutu to Mhlatuze water management areas (Turpie et al. 2010). The value of water usage was estimated based on the replacement cost of having to pay for water in containers from local vendors. This was estimated to be approximately R0.26 per litre or R260 per m3 (taken from Turpie et al. 2010).

It was estimated that a total of 27 500 litres of water per year per household were collected from rivers and streams. The average water usage across the EMA was estimated to be 24 m3 per km with an average value of R6 280 per one kilometre stretch of river or stream. This equated to a total usage of just over 122 million litres of water per year extracted from rivers and streams within the EMA with a total value of R32 million.

The households with the greatest reliance on rivers and streams are located predominantly in the sub-places located in the outer-west and southern planning regions (Tribal Lands) and sub-places adjacent to the larger river catchments such as the uMngeni and in poorer areas such as KwaMashu and Inanda where households in these sub-places are collecting up to approximately 750 m3 of water per kilometre stretch of river (Figure 3.2). In areas with the highest usage, this equates to approximately R361 000 per kilometre per year.

3.4 Sand

Sand is harvested commercially and for subsistence purposes from rivers and estuaries in the EMA for building and construction. A significant percentage of these mining operations are known to operate illegally. Both the large number of sand permits issued over recent years and the illegal and unregulated activities have raised concerns over the long-term sustainability of sand extraction in the EMA and implications for coastal erosion (CSIR 2008). The CSIR's (2008) comprehensive study on this issue found that the rivers of the EMA would naturally yield some 480 -720 000 m3 of sand per year, which would have provided an important supply of sand to the beaches of the Durban Bight. However, about a third of this yield is now trapped in 12 large dams, and an estimated 400 000 m3 is removed annually in sand mining operations, leaving the beaches starved of sand. While sand is valuable as a resource, their study found that its value was outweighed by the damage costs being incurred, and it was recommended that estuary and riparian sand mining be stopped altogether. Thus we have not included sand as an extractive resource in this valuation study.

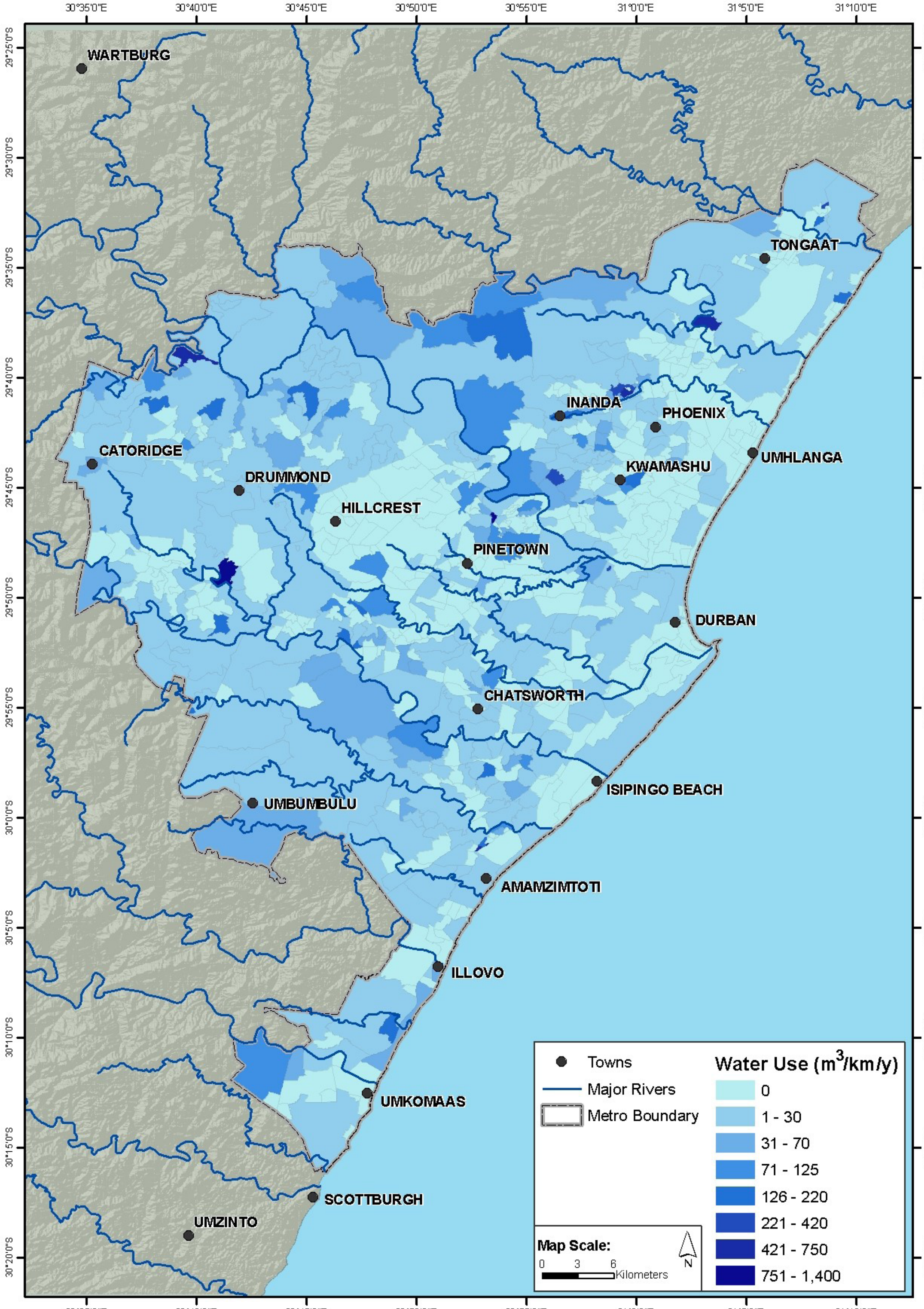

Figure 3.2 Estimated amount of water extracted from rivers and streams per sub-place in the EMA (m3 per km per year)

3.5 Woody resources

Fuelwood is a dominant source of energy used in rural households in South Africa. Within the EMA the majority of households live in urban areas with a direct electricity supply. However, there are areas in the EMA that have a significant rural and peri-urban population that rely heavily on fuelwood as a source of energy for cooking and heating. Due to limited financial resources in these rural and peri-urban areas, households rely on fuelwood as a cheaper alternative to electricity and paraffin. The dependence on fuelwood is known to be especially high in the traditional authority areas in the outer-west and southern planning regions of the EMA. However, there is not much information on usage levels in these areas. Wooden poles are harvested predominantly in the traditional authority areas too, for the construction of houses, fences and for other building infrastructure. Again, there is not much information about pole harvesting rates. It was assumed that the vegetated areas in and around the tribal land are the most impacted and also the most degraded due to the demand for woody resources in these areas.

In order to determine the sustainable supply of fuelwood and poles, stand volumes for each vegetation type within the EMA were calculated by using basal area and canopy height data collected by Glenday (2007; Table 3.3). Volume is generally estimated from dimensional variables such as diameter and height in the form of linear equations that take into account local vegetation form. However, in the absence of localised equations, cubic volume of wood for standing vegetation may be estimated using the following simplified equation (Magnussen & Reed 2004):

Volume (m^3/ha) = basal area (m^2/ha)×canopy height (m)/3

While this equation may somewhat overestimate or underestimate the volume of certain woody vegetation with different forms, it nevertheless provides a first approximation for determining stand volumes in the EMA.

Table 3.1 Tree volumes calculated for forest and woodland/thicket habitats in the EMA. Volumes were calculated using data collected by Glenday (2007).

General Description	Detailed Description	Volume (m3/ha)
Forest	Coastal	154.7
Forest	Dune scrub	57.3
Forest	Feral Plantations	104.3
Forest	Scarp	145.6
Forest	Riverine	145.6
Forest	Swamp	212.8
Forest	Transitional	25.3
Thicket	Dry valley thicket or Broadleaved woodland	45.9
Thicket	Transitional	10.5
Woodland	Closed	14.4
Woodland	Open	4.0
Estuary	Mangrove Forest	260.5
Estuary	Swamp Forest	212.8

Basal area and height data were not collected for mangrove forests in the Glenday (2007) study. Therefore volumes were estimated using data from associated literature for mangrove forests (Kairo 2001, Kairo et al. 2002, Ajonina et al. 2014) and an average volume of 260.5 m3/ha was used (Table 3.3). A sustainable yield of 3% of standing crop was applied for all vegetation classes. This estimate was based on the finding that the sustainable biomass harvesting rates for most of the ecosystems found in the peri-urban/urban areas of the EMA are 2-4% of standing biomass per annum (Glenday 2007) and Shackleton (1993) found the same when studying harvesting rates in Limpopo.

The amount of standing woody volume that was physically utilisable was assumed to be 90% for fuelwood and 15% for poles (Barnes et al. 2005), allowing for a component of the standing volume to be assumed unsuitable for harvesting. Woody resources were valued by using average prices of fuelwood and poles recorded in surveys and in the literature from South Africa, Botswana and Namibia. Prices were adjusted to 2015 Rands where necessary. Prices for fuelwood and poles were obtained from LaFranchi (1996), Loxton, Venn & Associates (Botswana, 1986), Ntshona (2002), Shackleton et al. (2002a), and Barnes et al. (2005). An average of R1058 per m3 for fuelwood and R882 per m3 for poles were used.

A total of 44,000 m3 of fuelwood was estimated to be the sustainable output per year in the EMA, with an estimated total value of R46.5 million (Table 3.4). Forested areas and thicket have the highest value and supply 60% and 37% of the fuelwood output respectively. Estuarine forests have the highest per hectare value at R3 400 and woodland the lowest at R266 per hectare. The average value per hectare for fuelwood across the EMA is R1 707 (Table 3.4). The largest vegetation patches where fuelwood can be harvested are located in the outer-west and southern planning regions on traditional authority land (Figure 3.3).

Table 3.3 Estimated total value (R million/year) of fuelwood yields in different vegetation types in the EMA

Vegetation Type	Vegetation sub-types	Available Area (ha)	Total fuel-wood (m3)	% of total	Total Value (R million/y)	Average value per ha (R/ha)
Estuarine Forest	Swamp & mangrove	114	345	<1	0.37	3 380
Forest	Coastal, scarp, transitional, dune and swamp	8 765	26 308	60	27.84	2 470
Wetland	Riparian	8	16	<1	0.02	2 079
Sub-tropical Vegetation	Dune	11	13	<1	0.01	1 230
Thicket	Dry valley thicket, open, closed and dune	15 884	16 216	37	17.16	816
Woodland	Closed, open, transitional	9 247	1 112	3	1.18	266
TOTAL		**34 030**	**44 011**		**46.57**	**1 707**

Figure 3.3 Estimated annual sustainable fuelwood output (m3/ha) from different habitats in the EMA

A total of almost 7500 m3 of poles can be sustainably harvested for construction purposes in the EMA each year. This equates to a total estimated value of R6.5 million (Table 3.5). The amount of wood harvested for poles to be used in the construction of houses and fences is much lower than the amounts of fuelwood harvested. This is because only larger trees and certain shrubs are able to supply timber that can be used in construction. It was also assumed that fewer people collect poles, whereas those relying on fuelwood would be significantly higher. Similarly to fuelwood, forested areas and thicket supply the majority of poles and these vegetation types are predominantly located in the outer-west and southern planning regions (Figure 3.4).

Figure 3.4 Estimated annual sustainable timber pole output (m3/ha) from different habitats in the EMA

Table 3.4 Estimated total value (R millions/year) of timber pole yields in different vegetation types in the EMA

Vegetation Type	Vegetation sub-types	Available Area (ha)	Total Poles (m3)	% of total	Total Value (R million/y)	Average value per ha (R/ha)
Estuary Forest	Swamp & mangrove	114	58	<1	0.05	470
Forest	Coastal, scarp, transitional, dune & swamp	8 766	4 487	60	3.96	360
Wetland	Riparian	8	3	<1	0.00	289
Sub-tropical Vegetation	Dune	11	2	<1	0.00	171
Thicket	Dry valley thicket, broadleaved woodland, closed & dune	15 884	2 703	36	2.39	113
Woodland	Closed, open, transitional	9 247	185	2	0.16	37
TOTAL		**34 030**	**7 437**		**6.57**	**240**

3.6 Food and medicinal plants

The demand for indigenous medicines in the eThekwini Municipality has always been high (Mander 1998) and forms an important part of traditions and culture in many households. In 1998, Mander estimated that households were spending between 4 - 8% of their annual incomes on indigenous medicines in KwaZulu-Natal. The same study found that urban consumers believed that the demand for indigenous medicines would not decrease but would remain stable or increase in the future as it was not considered an alternative to western medicine and was considered essential for everyday welfare (Mander 1998).

Medicinal plants are collected from wild plant stocks that are located in a number of different vegetation types within the EMA. The harvesting of wild plants is not managed and little cultivation of these plants takes place (Mander 1998). Bulbs, roots, whole plants, bark and leaves are collected from a variety of indigenous wild plants. The wild stocks in the EMA have been severely depleted and degraded as a result of the high demand and the lack of any resource management. The unsustainable use of medicinal plants has led to a decrease in supply and the loss of some certain scarce plants. Unsustainable commercial medicinal plant harvesting has caused habitat degradation and species mortality in a number of areas within the EMA (EPCPD 2012). The most extreme form of this is the mass ring-barking of trees, resulting in significant tree mortality in woodland and forested areas. Although medicinal plants are still commercially sold in the eThekwini Municipality, it is expected that a significant proportion of the medicine being sold is brought in from outside of the EMA and commercial harvesters are having to travel greater distances to collect plants and/or to purchase stock from sellers in other areas of KwaZulu-Natal, Mpumalanga and the Eastern Cape.

There is very little quantitative information on sustainable yields and even the harvesting of wild foods and medicines. For medicinal plants, Mander (1998) estimated that yields of 0.78 kg/ha/y were possible in woodlands and grasslands of KwaZulu-Natal, and Turpie et al. (2007) estimated that medicinal bulbs and herbs could be harvested in the Drakensberg grasslands at a sustainable rate of 20 kg/ha/y at a value of R9.40/kg. An average of the two sustainable yield estimates was used and applied to both forests and grassland/woodland habitats at 10.4 kg/ha/y at a price of R15.80/kg.

Estimates of harvests of wild fruits and vegetables range from 32 – 53 kg/household/y (Cocks & Wiersum 2003) to 104 kg/hh/y (Shackleton & Shackleton 2004; fruit only), 128 kg/hh/year in Limpopo (Twine et al. 2003), 1254 kg/household/year in Lesotho (Lannas & Turpie 2009) and 5 kg/hh/y in peri-urban Cape Town (Lannas & Turpie 2009). For this study it was assumed that only households in peri-urban and traditional authority areas were harvesting wild fruits and vegetables and that the harvest rate would be similar to that of peri-urban areas in Cape Town. Therefore a conservative estimate of 5 kg/hh/year was used for this study (Lannas & Turpie 2009) at a price of R0.85/kg for wild vegetables and R1.60/kg for wild fruits (Turpie et al. 2010).

The sustainable output of wild food and medicinal plant products in the EMA each year is estimated to be approximately 300 000 kg with a total value of R4.7 million (Table 3.6). Forest, thicket, woodland and grassland areas all contribute significantly to this figure, with forests having the highest per hectare value at R101/ha. Freshwater wetlands also provide a number of medicinal plants but their supply in the EMA is compromised by the poor condition of a number of wetland areas. It is believed that this value is much lower than the sustainable provisioning value for the same area a decade ago. Figure 3.5 shows the sustainable output (kg/ha) of medicinal plants across the study area.

Table 3.5 Estimated total value (R million/year) of wild foods and medicinal plants in different vegetation types in the EMA

Vegetation Type	Vegetation sub-types	Available Area (ha)	Total Medicinal Plants (kg)	% of total	Total Value (R million/y)	Average value per ha (R/ha)
Grassland	Primary, secondary	8 097	33 499	11	0.53	62
Freshwater wetland	Floodplain mixed	3 818	9 926	3	0.16	41
Estuary Forest	Swamp & mangrove	114	595	<1	0.01	82
Forest	Coastal, scarp, transitional, dune & swamp	8 766	70 298	24	1.11	101
Wetland	Riparian	8	21	<1	0.00	41
Sub-tropical Vegetation	Dune	11	43	<1	0.00	62
Thicket	Dry valley thicket, broadleaved woodland, closed, dune	15 884	138 019	47	2.18	90
Woodland	Closed, open, transitional	9 247	44 552	15	0.71	78
TOTAL		**45 945**	**296 952**		**4.70**	**70**

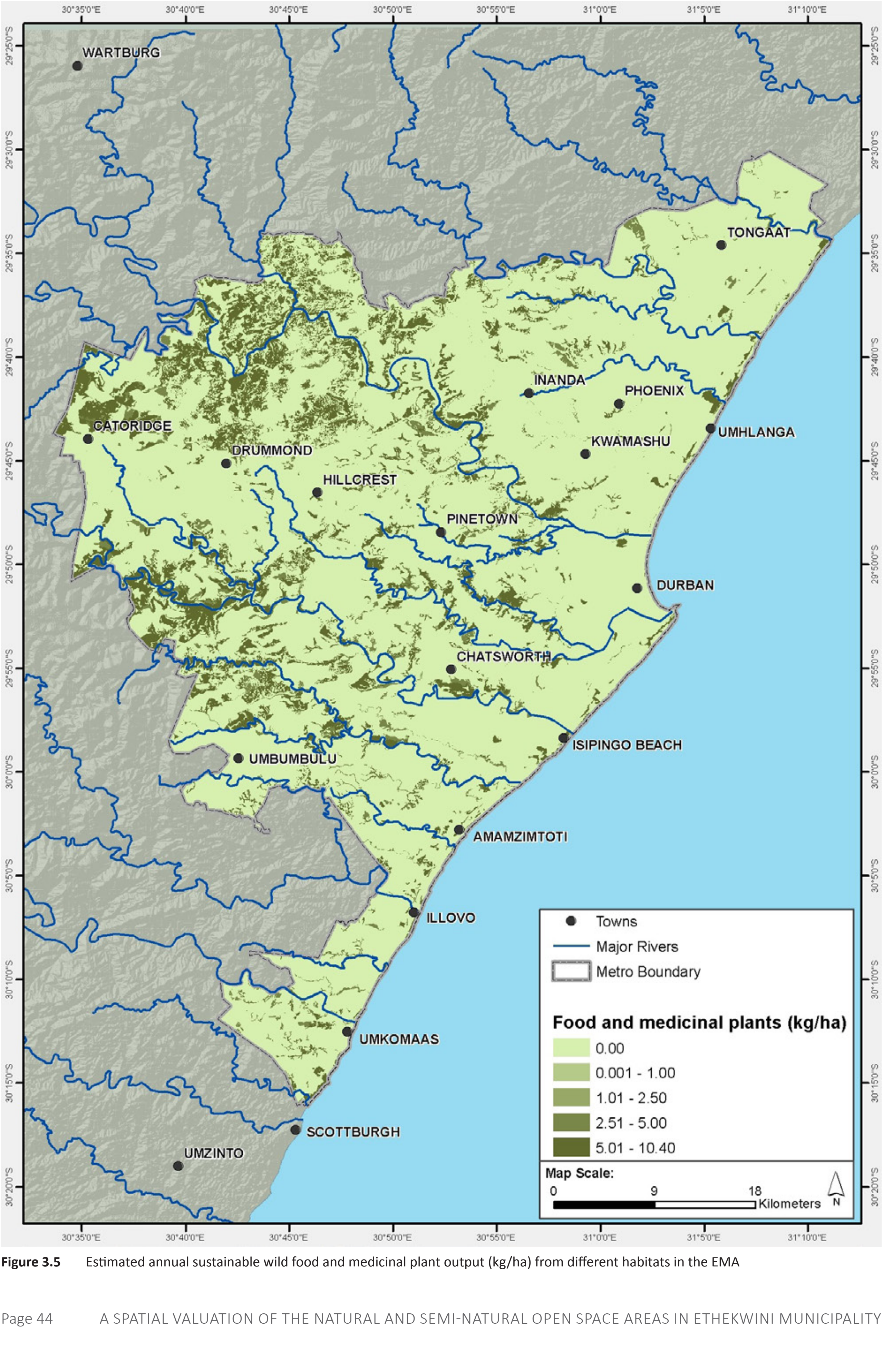

Figure 3.5 Estimated annual sustainable wild food and medicinal plant output (kg/ha) from different habitats in the EMA

3.7 Non-woody raw materials

Grasses and reeds are harvested for the production of crafts and for the construction of houses in rural and peri-urban areas. Most of the grass and reeds are harvested for the construction of roofs, and for crafts such as mats and baskets. There is very little information about the quantities and types of grasses and reeds that are harvested for these purposes within the EMA. In recent times more houses in the tribal lands and peri-urban areas tend to use corrugated iron and other building materials for roofs rather than the traditional thatching grass. This could be a result of a decreasing supply of this resource or it could be a result of cheaper, more accessible building materials.

Estimated were based on information from Twine et al. (2003), Turpie et al. (2007) and Mmopelwa et al. (2009). Twine et al. (2003) found that on average households in a village in Limpopo were sustainably harvesting just over 10 bundles of thatching grass per year, which equated to 30 kg/ha. Turpie et al. (2007) found that thatching grass was patchily distributed across the southern Drakensberg grassland region and provided on average 20 kg/ha. Mmopelwa et al. (2009) estimated the direct use value of certain plants in three villages adjacent to the Okavango Delta and found that the harvesting of thatching grass and reeds was sustainable with an estimated average harvest of 28 kg/ha for thatching grass and 70 kg/ha for reeds. It was assumed that the harvesting of reeds and grasses in the EMA would be less than the harvesting rates estimated by Mmopelwa et al. (2009) for the Okavango Delta but similar to those estimated by Turpie et al. (2007) and Twine et al. (2003). Therefore for the EMA a sustainable harvest of 24 kg/ha/y was applied at a price of R6.70 per kg, taken from Turpie et al. 2007.

It is estimated that the sustainable output of reeds and grasses in the EMA is just over 200 000 kg with a total value of R1.4 million (Table 3.7). Grassland areas contribute 77% of the output and freshwater wetland areas 23%. Grassland habitats are scattered across the EMA, with the largest patches being found in the outer-west region close to Cato Ridge and areas north of Inanda (Figure 3.6).

Table 3.6 Estimated total value (R million/year) of grasses and reeds in different vegetation types in the EMA

Vegetation Type	Vegetation sub-types	Available Area (ha)	Total Grass & Reeds (kg)	% of total	Total Value (R million/y)	Average value per ha (R/ha)
Grassland	Primary, secondary	8 097	154 609	77	1.04	121
Freshwater wetland	Floodplain mixed	3 818	45 811	23	0.31	81
TOTAL		**11 914**	**200 419**		**1.35**	**101**

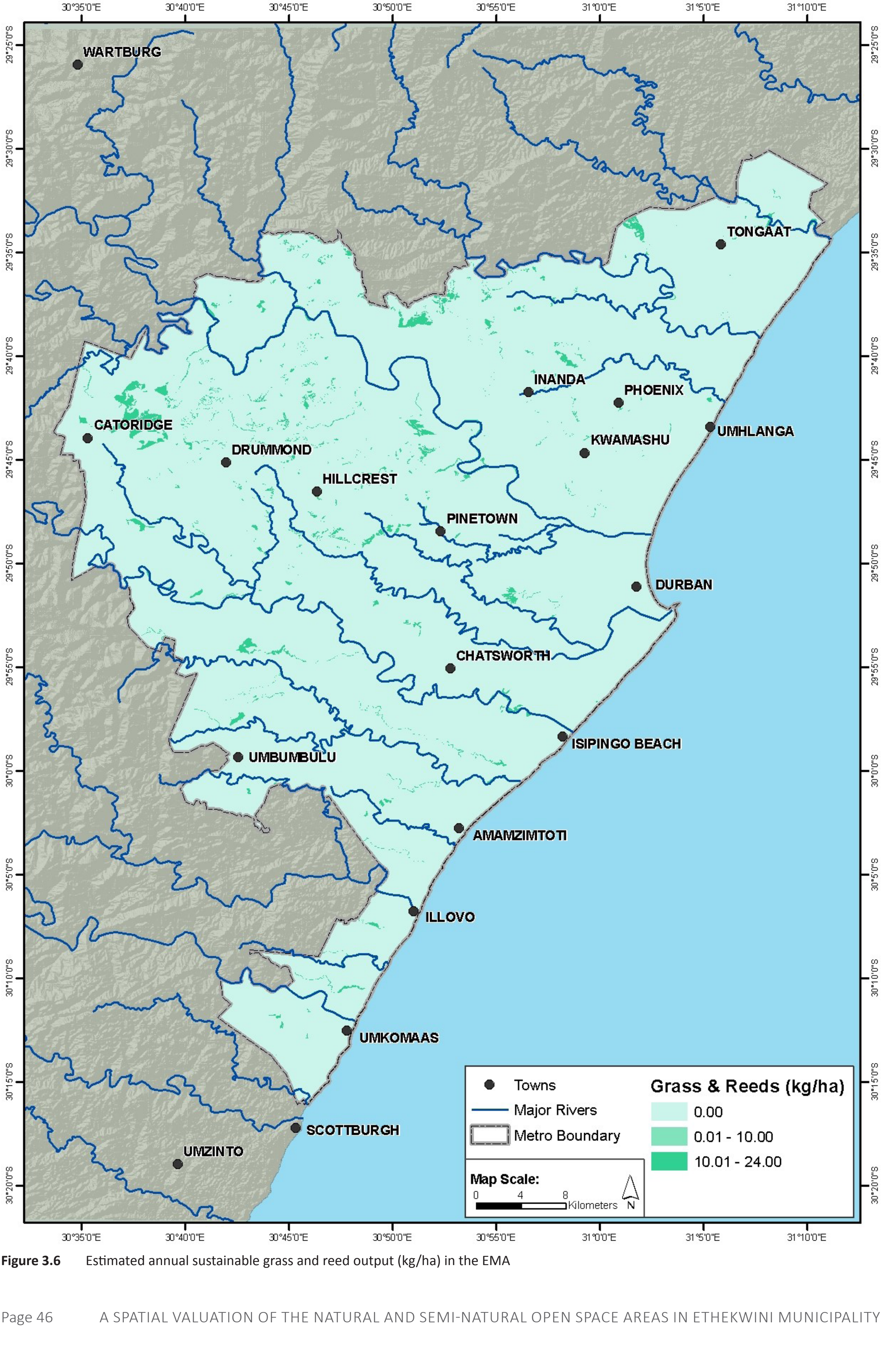

Figure 3.6 Estimated annual sustainable grass and reed output (kg/ha) in the EMA

3.8 Bush meat

Communities living in the rural areas of the EMA are known to hunt for wild mammals and birds. However, a significant portion of this hunting is thought to be illegal and takes place on protected and private land, often with packs of dogs and the use of snares (Grey-Ross et al. 2010). Small antelope, rodents and birds are the most commonly caught wild meat (Kaschula & Shackleton 2009) but not much is known about the magnitude of off-take by local communities in the rural areas within the EMA. Illegal hunting with packs of dogs is an increasingly concerning problem in many parts of KwaZulu-Natal where people with dogs are hunting wild animals on private and protected lands for gambling purposes and not for subsistence (Grey-Ross et al. 2010). These hunts involve groups of owners and their dogs taking bets on whose dog will kill the animal first. These groups can be large and the money involved quite substantial. This method of hunting is completely unselective and there are concerns about the impacts overhunting is having on some of the more rare and endangered mammals, such as the Oribi antelope (Ourebia ourebi).

Studies of wild meat harvesting (mainly mammals and birds) have found offtake rates in the region of 209 kg/km2/y in coastal regions of South Africa (Shackleton et al. 2007), 268.6 kg/km2/y or 3 kg/person/y in the inland communal areas of the Eastern Cape (Kaschula & Shackleton 2009) and 151 kg/km2/y in the Kat River Valley (Shackleton et al. 2002b). In all cases the harvesting rate did not appear to be unsustainable. Although the EMA contains a significant area of rural landscapes, these tend to be densely populated and the vegetation patches small and fragmented, and probably support lower densities of animals than in the areas that have been previously studied. We therefore conservatively estimated a sustainable yield of 104 kg/km2/y; an average of the lower estimates of wild meat harvesting from other regions in the country. An average price of R21.90 per kg was used based on prices taken from Shackleton et al. 2007 and Turpie et al. 2010.

The annual sustainable hunting offtake was estimated to be 26 000 kg of wild meat and birds with a total estimated value of R565 500 (Table 3.8). Forest, thicket and woodland habitats are estimated to be able to supply the majority of this output. These values are relatively low when compared to other studies, however they are based on sustainable offtake levels and do not consider the illegal hunting of mammals on private and protected lands. Therefore these levels are assumed to be realistic in a predominantly urban and fragmented area. The spatial representation of hunting across the EMA is shown in Figure 3.7 and as with the other natural resources, the highest levels of output are associated with habitats located in the outer-west and southern planning regions where natural habitat patches are larger, less fragmented and on communal land.

Table 3.7 Estimated total value (R million/year) of hunting in different vegetation types in the EMA

Vegetation Type	Vegetation sub-types	Available Area (ha)	Total Hunting (kg)	% of total	Total Value (R million/y)	Average value per ha (R/ha)
Grassland	Primary, secondary	8 097	1 353	5	0.03	3.50
Freshwater wetland	Floodplain mixed, riparian	3 826	191	<1	0.00	1.10
Estuary Forest	Swamp & mangrove	88	4	<1	0.00	1.10
Forest	Coastal, scarp, transitional, dune and swamp	8 766	6 639	26	0.15	7.70
Thicket	Dry valley thicket, broadleaved woodland, closed, dune	15 884	13 728	53	0.30	12.10
Woodland	Closed, open, transitional	9 247	3 901	15	0.09	8.00
TOTAL		**45 907**	**25 817**		**0.57**	**5.60**

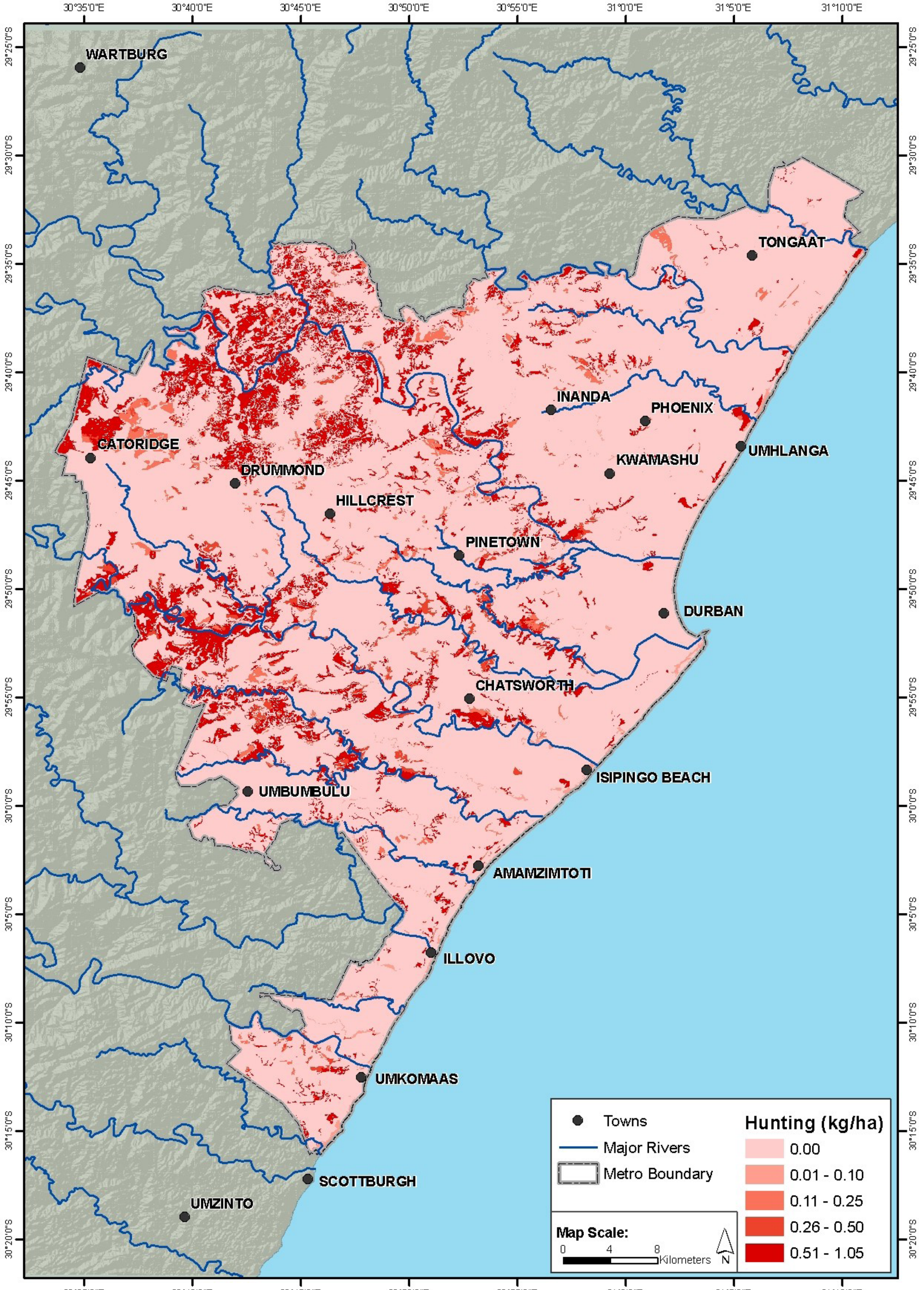

Figure 3.7 Estimated annual sustainable hunting output (kg/ha) across the EMA

3.9 Fishery resources

A variety of fishery resources are harvested from rivers, estuaries and the marine environment both commercially and for subsistence. A number of fisheries operate along the KwaZulu-Natal coastline including the commercial line fisheries, subsistence line fishery, recreational line fisheries, small scale commercial net fisheries, recreational net fisheries, illegal gill and seine net fishery, and inshore invertebrate fisheries (Everett 2014). There has been relatively few traditional or artisanal fisheries along the KwaZulu-Natal coastline due to the high-energy nature of the coastline making fishing with low technology difficult, and the fact that historically the Zulu people who moved to the coast were traditionally cattle farmers (Everett 2014). However, there is a section of society living in the EMA that do rely on fishery resources. There are three main subsistence fisheries found in the EMA; the subsistence line fishery, the illegal gill net fishery and the small-scale rocky shore and sandy beach invertebrate fisheries.

Subsistence fishers are usually referred to as poor, unemployed people who harvest fish and other aquatic organisms in close proximity to where they live as a means of meeting their basic needs of food security (Branch et al. 2002). Usually these fishers fish along the sea or estuary shoreline and cannot afford vessels. They use basic equipment and generally catch their own bait, such as sand prawns, red bait and mussels (Everett 2014). Most of the fish that are caught are for personal or family consumption and are not sold. Only when catches are large will they either be sold or bartered (Everett 2014). Estimating the total number of "true" subsistence fishers along the coast is difficult. In recent years there has been an increase in the number of people operating under the pretence of being subsistence line fishermen so as to exceed daily bag limits and to sell their fish at local markets (Everett 2014). As explained by Everett (2014) this has resulted in serious challenges in trying to successfully identify and manage true subsistence line fisheries in KwaZulu-Natal.

Roving creel surveys conducted along the coast of KwaZulu-Natal have shown that a relatively small percentage (3-6%) of the total number of shore fishers are "true" subsistence line fishers (Dunlop 2011). Using this data Everett (2014) predicts that the best estimate of total subsistence line fishers along the KwaZulu-Natal coast is approximately 4000 people. It is estimated that the annual amount of fish harvested in estuarine and marine environments by subsistence line fishermen along the KwaZulu-Natal coast is around 23 tons (Everett 2014). The main species that are caught include shad Pomatomus saltatrix (22%), grey grunter Pomadasys urcatum (15%), stonebream Kyphosus lithophilus (14%), largespot pompano Trachinotus botla (12%), blacktail Diplodus capensis (11%), karanteen Sarpa salpa (8%) and stumpnose Rhabdosargus spp. (6%; WIOFish 2013, Everett 2014). These figures relate only to the managed component of the fishery, it is expected that the catch could be higher as the true numbers of subsistence fishermen are not known. There is limited information about the value of this fishery. Everett (2014) reported that the total annual catch value ranged from R150 000 to R920 000 based on estimates from studies conducted in 2010 and WIOFish Annual Report (2013).

Illegal gill net fishing has been taking place in the rivers and estuaries of KwaZulu-Natal for decades (Everett 2014). The gill-nets used in the region range in length from 10 – 1000 metres depending on location (Everett 2014). The nets are usually set along estuary margins or across estuary or river channels targeting a wide range of different fish species. The majority of the people involved in this fishery are unemployed, poor people that live within close proximity to estuaries or large river systems. Most of the illegal gill netting in KwaZulu-Natal takes place in the St Lucia iSimangaliso area and associated systems and there are only a few estuaries in the EMA where illegal gill netting has been known to occur, namely Durban Bay and the uMngeni Estuary, however Everett (2014) notes that there has been periodic netting in many of the smaller estuaries along the KwaZulu-Natal coast too. Because the fishery is illegal, effort and participation data is difficult to estimate or collect. The fishery has high level impacts on resources, is considered to be unsustainable and was therefore not valued as part of this study.

Small-scale and subsistence fishers living along the KwaZulu-Natal coastline collect a variety of intertidal and sandy beach organisms, including both mobile and sessile invertebrates (Everett 2014). In total there are approximately 556 invertebrate fishers along the coast but 300 are estimated to be living within the iSimangaliso Wetland Park and the remainder (256) are spread along the rest of the KwaZulu-Natal coast (Everett 2014). The harvesting of intertidal and sandy beach organisms is usually undertaken by women and children. WIOFish (2013) reported that the small-scale invertebrate fishery caught in total 8 043 kg of mangrove crabs which equates to over 400 000 individual crabs, 200 kg of ghost crab, 100 kg of mole crabs, 1 700 kg of mixed invertebrates and 9 000 kg of mussels. The mixed invertebrates that are harvested include redbait, urchins, whelks, octopus, sea cucumbers and limpets (Everett 2014).

Table 3.8 Summary of the subsistence line and invertebrate fisheries along the KwaZulu-Natal coastline in terms of numbers, annual catch, annual effort and value in 2012 (Source: Everett 2014)

Fishery	Number of fishers	Total Annual Catch	Total Annual Effort	Total value of catch
Subsistence Line Fishery	4000	23 tons	48 000 days	R920 000
Subsistence invertebrate fisheries	556	19.3 tons	unknown	R445 000

There is very scant information on subsistence fishing in the rivers of the EMA. Most of the information available relates to fishing in estuaries and along the coastline. In the Olifants, Inkomati and Usutu to Mhlatuze Water Management Areas (Turpie et al. 2010), fishing was found to be marginal activity with only 4% of households in the former homeland areas sampled being involved in fishing. Freshwater catches in this survery region comprised mostly of cichlid Tilapia rendalli and Sarotherodon mossambicus, tiger fish Hydrocynus vittatus, barbel Clarias gariepinus and mud suckers Labeo rosae and L. rubropunctatus (Turpie et al. 2010). While some freshwater fishing is likely to occur in the EMA, its value is likely to be negligible.

Fishing in the estuaries of the EMA is more common. Subsistence fishing effort and values have been estimated for a number of South African estuaries in a rapid national assessment (Branch et al. 2002), but data were patchy and no comprehensive studies have taken place. Using these data, Turpie et al. (2010) determined a relationship between fishing value and area (R125 000 per Ln(A), where A = area, in ha) in order to estimate the value of estuarine subsistence fishing in northern KwaZulu-Natal. This was used to estimate potential value, and adjusted using estuarine health scores from the National Estuary Biodiversity Assessment (van Niekerk & Turpie 2012), to provide an order-of-magnitude estimate of the provisioning value of these resources in the EMA.

The subsistence fishery value associated with estuaries in the EMA was estimated to be close to R6.3 million (Table 3.10), with Durban Bay and the uMngeni Estuary contributing the most to this value. Whilst these two estuaries are considered to be degraded, they are both large open estuarine systems that are known to have diverse and resilient fish communities. A number of smaller estuaries which are in a highly degraded state such as the iSipingo and aManzimtoti were considered unlikely to support subsistence fishing activities. The fish communities in these estuaries have been reported to be poor with very low numbers recorded in the system and low carrying capacities (Forbes & Demetriades 2008, van Niekerk & Turpie 2012).

Table 3.9 Summary of the subsistence line and invertebrate fisheries along the KwaZulu-Natal coastline in terms of numbers, annual catch, annual effort and value in 2012 (Source: Everett 2014)

Estuary	Health category (Forbes & Demetriades 2008)	Ecological health category	Total Annual Effort	Total value of catch
uTongati	Highly degraded	E	0	0
uMdloti	Poor	D	617 700	4 412
oHlanga	Poor	D	603 500	4 828
uMngeni	Highly degraded	D	679 800	2 955
Durban Bay	Highly degraded	D	851 700	936
iSiphingo	Highly degraded	F	0	0
eziMbokodweni	Highly degraded	E	0	0
aManzimtoti	Highly degraded	D	0	0
Little aManzimtoti	Highly degraded	D	0	0
iLovu	Fair	C	677 000	3 009
uMsimbazi	Good	B	569 200	5 992
uMgababa	Good	B	593 100	5 158
Ngane	Fair	B	99 900	9 083
uMkhomazi	Fair	C	616 800	4 437
uMahlongwane	Good	B	397 300	16 552
iMahlongwa	Fair	C	555 300	6 533
TOTAL			**6 261 300**	

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IV. REGULATING SERVICES

4.1 Introduction

Regulating services relate to the capacity of natural and semi-natural ecosystems to regulate essential ecological processes and life-support systems through bio-geochemical cycles and biospheric processes (de Groot et al. 2002). Regulating services enable natural ecosystems to supply provisioning services such as food and water as they maintain the capacity of system to continue to function over a range of conditions (Simonit & Perrings 2011). They have been identified by the Millennium Ecosystem Assessment (MEA) as the least understood but potentially most valuable of services provided by ecosystems (MEA 2005, Simonit & Perrings 2011). In addition to maintaining ecosystem health, these regulation functions provide numerous services that have direct and indirect benefits, such as clean water and air, soil development and stabilisation, climate regulation, agricultural support and biological control. However, because many of the benefits are indirect, they are often not recognised until they are degraded, disturbed or completely lost (de Groot et al. 2002).

Amongst the most important examples of regulating services are those that relate to water. The hydrological services valued as part of this study are flow regulation and water quality amelioration (nutrient and sediment retention). The valuation and mapping of these two services required complex hydrological modelling, which is outlined in detail in Appendix 2. Other regulating services valued and mapped in this study include carbon storage, nursery function (i.e. contribution to marine fisheries), and agricultural support.

4.2 Carbon storage

Climate change caused by increases in the emissions of greenhouse gases will carry a cost of about 2 – 7% of Gross Domestic Product (GDP) in different parts of the world by 2050 (Fankhauser & Tol 1997). Natural systems are understood to make a significant contribution to global climate regulation through the sequestration and storage of carbon. About half of the biomass of vegetation, both above and below ground, comprises carbon. Furthermore, carbon accumulates in the soils as a result of leaf litter. When natural systems are degraded or cleared, much this carbon is released into the atmosphere, especially if the degradation is for fuel wood production or due to burning for grazing (Hoffa et al. 1999). These emissions contribute to global climate change, which is expected to lead to changes in biodiversity and ecosystem functioning, changes in water availability, more frequent and severe droughts and floods, increases in heat-related illness, and impacts on agriculture and energy production (IPCC 2007). These impacts will affect economies and human wellbeing on a global scale, but more so in developing countries that are more reliant and land and natural resources (Tol 2012). Adaptation to these changes could come at a high cost. The conservation and restoration of natural systems thus helps to reduce the rate at which greenhouse gases accumulate in the atmosphere and the consequent impacts of climate change. This is a global benefit.

Concerns about the loss of natural systems and the impacts of climate change have motivated efforts to quantify the role and value of these ecosystems in the global carbon cycle, and have also encouraged political efforts (Glenday 2007, Davies et al. 2011, Timilsina et al. 2014). The eThekwini Municipality has made a strong commitment to addressing the causes and impacts of climate change and the subsequent loss of ecosystem goods and services (Glenday 2007). The eThekwini Municipality's Environmental Management Department (EMD) has established the eThekwini Environmental Services Management Plan (EESMP) and is a member of the International Council for Local Environmental Initiatives (ICLEI) Cities for Climate Protection (CCP) Program. As part of this program the municipality has been working towards climate change mitigation and adaptation, focusing on land cover management and urban land use planning.

The capacity for carbon sequestration and storage varies between different types of ecoystems and in different locations, and can be estimated based on a combination of satellite data and ground-level sampling. In a study conducted in 2005/6, Glenday (2007) estimated that the total amount of carbon stored in all the major vegetation types of the EMA open space system is 6.6±0.2 million tonnes of carbon (Mt C) equivalent, or 24.3±0.9 million tons of carbon dioxide (Mt CO2). Some 8 400 – 9 800 tonnes of carbon are sequestered per annum (tC/y). The spatial distribution of this service is shown in Figure 4.1.

Carbon densities (tons carbon per hectare, tC/ha) for all the major landcover classes in the EMA, as calculated by Glenday (2007), were used for this study (Table 4.1). Glenday (2007) determined the mean carbon density per carbon pool for all vegetation types sampled in the EMA. For example, forest carbon densities were determined for above ground biomass, below ground biomass, coarse deadwood, litter, herbaceous vegetation and soil to a depth of 30cm, whereas grassland carbon density was calculated based on above ground biomass, below ground biomass, and soil to a depth of 30cm. The carbon densities were assigned and mapped to specific vegetation types and to more general land cover types using the most recent D'MOSS and landuse GIS layers. Heavily urbanized areas were assumed to not have any carbon storage.

A recent estimate puts this value at US$29 (US$1 equal to R11.84 in May 2015) per tonne of carbon in 2015, and this is expected to increase by about 2% per year (Tol 2012). While developed countries emit more carbon, developing countries are expected to incur proportionally greater costs in terms of percentage of GDP.

Estimates of the social cost of carbon are based on the impacts of climate change on country GDP outputs aggregated at a global scale. The most recent estimate placed the social cost of carbon at US$34 per ton of CO_2 (in 2015 USD; Nordhaus 2017;US$1 = R11.84). While developed countries emit more carbon, developing countries are expected to incur proportionally greater costs in terms of percentage of GDP. Nordhaus (2017) estimated that of the total global cost of carbon, only 3% would be borne in Africa. Therefore the cost that would occur to South Africa would be proportional to its GDP contribution to Africa, scaled by level of vulnerability to climate change. The Notre Dame Global Adaptation Initiative (ND-GAIN) vulnerability index was used to scale GDP contributions across Africa. The vulnerability index measures a country's exposure and sensitivity to negative impacts of climate change. The overall vulnerability index is scored based on six life-supporting sectors; food, water, health, ecosystem services, human habitat and infrastructure. Based on this index, it was estimated that South Africa's share of the social cost of carbon borne by Africa would be 11.7%.

Thus, while the global damage costs that this amount of carbon could produce are over R9.8 billion, the damage costs to South Africa resulting from a loss of the carbon stocks within the EMA would be approximately R34.3 million per annum.

Table 4.1 Carbon densities (tC/ha) for land cover classes in the EMA (Source: Glenday 2007)

Landcover	Sub-Type	Carbon density (tC/ha)
Woodland	Dry Valley Thicket/Broadleaf	121
Wooded Grasslands	Coastal Bushclump Grassland	82
	Acacia Savanna, Protea and Faurea Woodland	66
Forest	Coastal Scarp Forest	199
	Transitional Forest	103
	Coastal Lowland Forest	166
	Dune Scrub and Dune Forest	133
	Riverine Forest	165
Wetland (non-woody)	Floodplains and freshwater wetlands	149
	Estuarine wetland	244
Wetland Forest	Swamp Forest	287
	Mangrove Forest	375
	Barringtonia racemosa & Hibiscus tiliaceus Forest	301
Grassland	Secondary grassland	75
	Primary grassland	62
Recreational	Parks, golf course & sports fields	102
Settlements	Sparse rural (disturbed woodland)	59
	Dense rural	15
Field crops	Fallow crop lands	75
	Commercial market gardening & cropland	37
Tree crops	Plantations	85
	Fruit trees	150
Utility	Cemetery	102
	Grassed road verges & reservoirs	46
Alien Vegetation	Alien Thicket	53
	Alien Woodland	92
	Feral Plantation	121

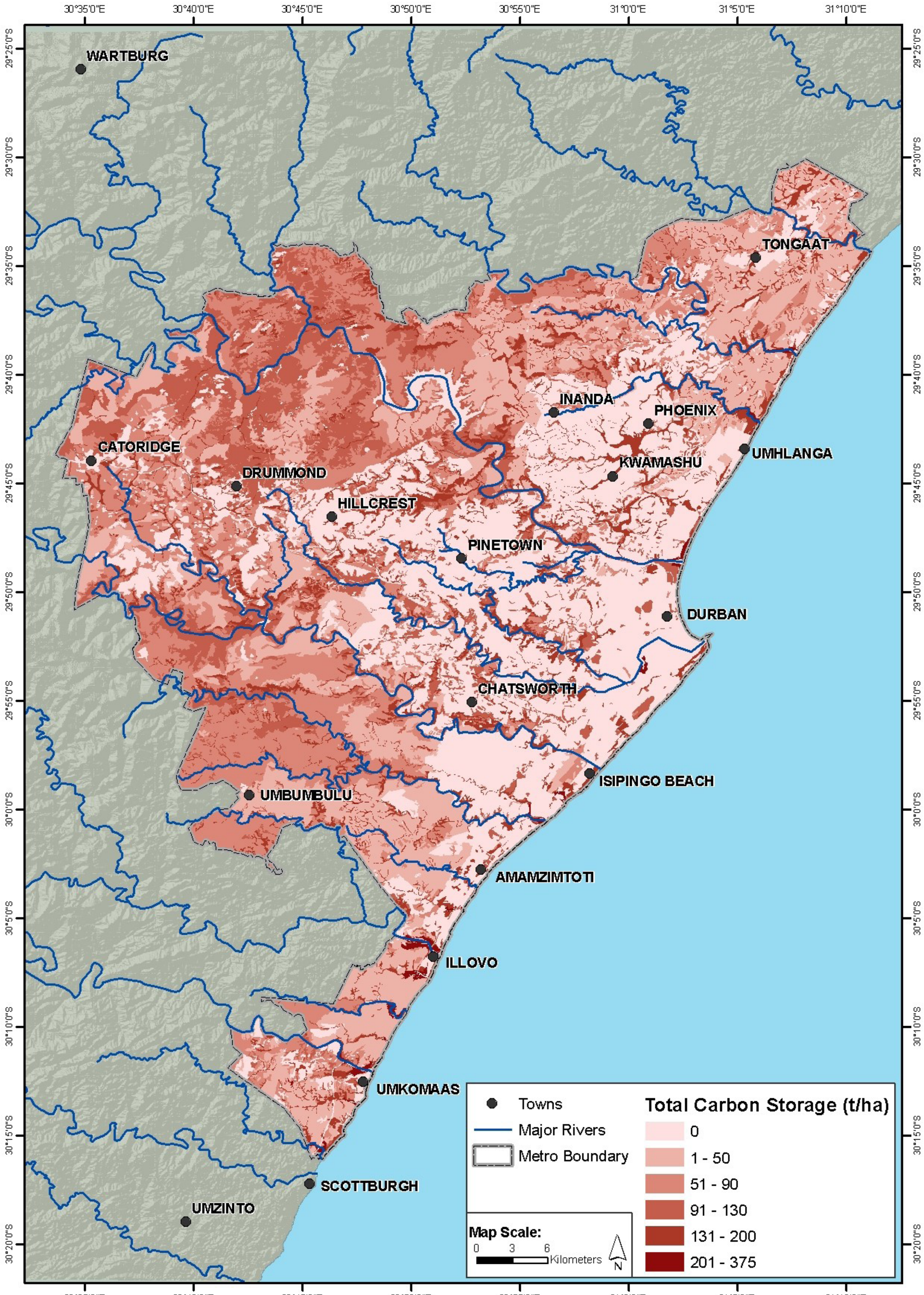

Figure 4.1 Total carbon storage (tons/ha)

4.3 Fisheries support (nursery function)

South African estuaries support several species of fish that are dependent on nursery areas for at least their first year of life (Lamberth & Turpie 2003). The capacity of estuaries to function as nursery areas is dependent on the condition of their habitats and their fish stocks. These, in turn, are dependent on the quantity and quality of freshwater inflows, the management of habitats, and fishing pressures within the estuaries. Estuarine fish species have been categorised according to their level of dependence on estuaries (Table 4.2), with the estuaries playing an important role for spceis in categories I and II. Most estuary-dependent fish species enter estuaries as larvae or post larvae (Whitfield & Marais 1999) and once the estuarine dependent phase is complete, they leave for the marine environment where they become available to marine fisheries, and upon maturity contribute to the spawning stock (Wallace 1975a,b). Some of the larger estuary systems, such as the uMngeni Estuary, are also known to provide an important nursery habitat for penaeid prawns. Adults spawn offshore, and once the eggs have hatched and developed to the post-larva stage, they enter estuaries where they reside as juveniles until they are ready to return to the sea (Forbes & Forbes 2013).

There are 16 estuaries in the EMA with a total estuarine open water area of approximately 972 ha, or 2.6% of the total KwaZulu-Natal estuarine open water environment. More information about these estuaries can be found in Appendix 1. In KwaZulu-Natal there are 71 estuary-associated fish species that are caught in fisheries (Lamberth & Turpie 2003). Fish diversity and abundance differs between estuaries of different sizes and types, with higher species richness associated with larger and permanently-open systems (Lamberth & Turpie 2003), such as Durban Bay and the uMngeni Estuary. However, there are a number of estuaries withi the EMA that have become severely degraded as a result of significant flow modifications, very poor water quality, habitat destruction and overfishing (DWA 2013a). This has affected their current contribution of each estuary to nursery value.

This study used catch data and associated economic value of recreational and commercial fisheries as described by Lamberth & Turpie (2003) in conjunction with more recent (2009/10) fishery survey data for KwaZulu-Natal fisheries that included updated estimates on participation, effort and average catches published by Dunlop & Mann (2012, 2013). The fish species included in the catch data were categorised based on their level of dependence on estuaries (Table 4.2). In the commercial fisheries, fish were valued at their market prices, whereas in the recreational fisheries, a value was assigned to fish equal to their market price multiplied by ratio of total expenditure to total market value of the catch. This was based on the assumption that differences in average market prices also reflected the relative value of the different species to recreational anglers. For the

Table 4.2 The five major categories and subcategories of fish that utilize South African estuaries (Whitfield 1994).

Category	Description
I	Estuarine species that breed in southern African estuaries:
	Ia. Resident species, no record of spawning in marine or freshwater environments
	Ib. Resident species that do have marine and freshwater breeding populations
II	Euryhaline marine species that normally breed at sea, with juveniles showing varying degrees of dependence on southern African estuaries:
	IIa. Juveniles dependent on estuaries as nursery areas
	IIb. Juveniles occur mainly in estuaries, but are also found at sea
	IIc. Juveniles occur in estuaries, but are usually more abundant at sea.
III	Marine species that occur in estuaries in small numbers, but are not dependent on these systems
IV	Freshwater species, whose penetration into estuaries is determined mainly by salinity tolerance
V	Catadromous species that use estuaries as transit routes between marine and freshwater environments, but may also occupy estuaries in some regions
	Va. Obligate catadromous species that require freshwater in their development
	Vb. Facultative catadromous species that do not require a freshwater phase in their development

A number of estuarine dependent fish species are exploited by recreational and commercial fisheries in the inshore marine area. KwaZulu-Natal is a sought after location for recreational shore- and boat-based angling. Many thousands of visitors come to KwaZulu-Natal annually to fish along the shore. This industry is of immense importance to the economy of the province and each fish caught effectively brings in much more revenue than would be obtained from the commercial catching and selling of the fish.

recreational fisheries, the gross output value of these fisheries was taken to be the expenditure by the fishers on their activities, which include expenditure in the accommodation and retail sectors, as well as on travel, which translates into direct gross income (turnover) in those sectors. In the absence of available data on the expenditure by recreational anglers, this was estimated based on the comprehensive study of McGrath et al. (1997). Current expenditure was estimated on the basis of average value generated per angler day. The economic value of the commercial fisheries was estimated based on the recent catch estimates and the landed catch value of the fisheries as a measure of gross output.

The data collected by Dunlop & Mann (2012, 2013) showed a 60% decrease in annual fishing effort within the recreational fishery compared to data collected in the earlier Lamberth & Turpie (2003) study. Effort and catch was also significantly lower for the commercial line fishery, but this was a result of implemented policy changes. Using the updated effort data and subsequent update for average value generated per angler per day an overall current value for recreational and commercial fishing was estimated.

Based on updated estimates of participation, effort and catch in KwaZulu-Natal fisheries, it is estimated that the recreational and commercial fisheries in K waZulu-Natal are worth R429 million (Table 4.3). Of this R350 million (or 82%) is attributable to recreational shore angling and only R16.6 million to the commercial line fishery. Recreational boat angling and charter angling is worth approximately R62.3 million.

To determine the value of the estuary contribution, the values of the species categorised by Whitfield (1994) as Category II were multiplied by their estimated level of dependence on estuaries (Category IIa = 100%, IIb = 90% and Category IIc = 30%). The overall nursery value for estuaries in KwaZulu-Natal was estimated by multiplying the total fishery value for KwaZulu-Natal by the percentage contribution of estuary fish caught within each fishery.

In order to assign a nursery value to each individual estuary in KwaZulu-Natal the size of each estuary was multiplied by the fish health score (taken from van Niekerk & Turpie 2012) for each estuary to determine an overall "effective nursery area" for each estuary. The value for each estuary was then divided by the sum of all the KwaZulu-Natal healthy estuarine area and a percentage contribution of each estuary to nursery value was determined. From this a total nursery value for the EMA could be estimated by multiplying the overall nursery value in KwaZulu-Natal by the percentage contribution for each estuary. It should be noted that during the most recent comprehensive surveys and data collection for fisheries in KwaZulu-Natal (Dunlop & Mann 2012, 2013) St Lucia, the largest estuarine system in the country, was closed off from the sea and had been closed for almost ten years. It was therefore assumed that St Lucia over this period did not contribute to the nursery value along the KwaZulu-Natal coastline and was therefore removed from the analysis when determining individual estuarine contribution to nursery value. The percentage contribution of Kosi Bay to the overall nursery value in KwaZulu-Natal was also reconsidered based on the knowledge that the increase in traditional fish traps and their efficiency in trapping fish has a significant effect on the numbers of fish able to leave the estuary for the sea. It was assumed that Kosi Bay contributes only 10% of what it would if traditional fish traps were not in the estuary.

Updated catch data were not available for the recreational spearfish sector or the commercial net fishery in KwaZulu-Natal, and these fisheries were not included in this analysis. The estuarine contribution to the catch value in these two sectors was estimated to be comparatively small (R2.7 million) or just 1.3% of near shore fishery value attributed to KwaZulu-Natal estuaries by Lamberth & Turpie (2003). Commercial (legal) gill netting in KwaZulu-Natal was phased out with the allocation of medium-term commercial fishing rights in 2003 and the remaining commercial beach-seine operation near Durban lands very low volumes of fish, estimated at 7 tons by Beckley & Fennessy (1996).

Based on the estimated value of the fisheries and the percentage contribution of estuarine fish, the estimated total contribution of all KwaZulu-Natal estuaries to coastal and inshore marine fisheries was **R106.8 million** (Table 4.3). Applying estuary size and fish health scores to all estuaries in KwaZulu-Natal it was estimated that the overall contribution of estuaries in the EMA was **R11.4 million** (Table 4.4). This represents a 11% contribution to KwaZulu-Natal nursery value. uMkhomazi, Durban Bay, oHlanga and uMngeni have the highest percentage contribution and associated nursery value. Estuaries that are severely degraded and small in size, such as the iSipingo and Little aManzimtoti, contribute almost nothing (Table 4.4). The overall functionality of the EMA estuaries is approximately 35%, therefore two thirds of the value that these estuaries could provide to KwaZulu-Natal fisheries has been lost.

Table 4.3 Estimated participation, annual effort and catch in four KwaZulu-Natal near-shore fishing sectors based on data from (Dunlop & Mann 2012, 2013) and the associated KwaZulu-Natal fishery value and KwaZulu-Natal nursery value based on the amount and percentage of the total contributed by estuary-associated fish species

Fishery	Participation [1]	Annual effort [2]	Catch (t)	Value of Fishery	Total Value (R million/y)	Average value per ha (R/ha)
Shore-angling	54,685	801,692	263	349.5	30.5	106.60
Recreational boat angling	2,768	30,435	457	1.3	1.7	0.02
Charter boat angling	~100	5,898	245	61.0	0.11	0.07
Commercial line fishing	51	3,331	785	16.6	0.85	0.14
Total			**1750**	**428.4**		**106.8**

1: Shore angler participation is number of anglers; Boat fisheries are number of boats
2: Effort is shore angler-days.y-1, and number of boat launches. y-1

Table 4.4 Percentage contribution of estuaries in the EMA to KwaZulu-Natal nursery value and the estimated nursery value for each individual estuary based on size and fishery health scores.

Estuary	Fish Health Category (van Niekerk & Turpie 2012)	% contribution to KwaZulu-Natal nursery value	Nursery value (R millions)	R/ha/y
uTongati	E	0.03	0.04	10 084
uMdloti	E	0.22	0.24	8 403
oHlanga	E	0.14	0.15	13 445
uMngeni	D	1.46	1.56	18 487
Durban Bay	E	5.19	5.54	8 403
iSipingo	F	0.03	0.03	3 361
Mbokodweni	E	0.11	0.12	13 445
aManzimtoti	E	0.05	0.05	10 084
Little aManzimtoti	F	0.02	0.02	6 723
iLovu	C	0.78	0.84	23 529
Msimbazi	B	0.58	0.62	30 252
uMgababa	B	0.46	0.49	28 571
Ngane	C	0.04	0.04	23 529
uMkhomazi	D	1.22	1.30	18 487
uMahlongwane	C	0.15	0.16	25 210
iMahlongwa	D	0.14	0.15	20 168
TOTAL		**10.6**	**11.4**	

4.4 Agricultural Support (pollination)

Natural habitats support organisms that provide agricultural support services in the form of pollination and the control of agricultural pests. Crop pollination by insects is an essential ecosystem service that increases both the yield and the quality of crops (Melin et al. 2014). It has been estimated that as much as 30% of worldwide food production is reliant upon pollination by insects that rely on natural vegetation (De Groot et al. 2002). However, there has been relatively little empirical research carried out on natural systems' contribution to pest control. There are two subspecies of the indigenous honeybee Apis mellifera; A. m. scutellata occurs in the summer rainfall regions of South Africa and A. m. capensis is found in the winter rainfall regions. These honeybees are the most important pollinators of many South African crops because they can be managed by humans at the scale needed for large-scale commercial pollinator services.

Of the crops grown within eThekwini Municipality, many are wind-pollinated, including sugar and maize. In the case of root crops such as sweet potato and cassava, production is not directly dependent on pollination, since the plants are usually propagated with cuttings, although pollinators are required in breeding programmes. However, several crops are directly dependent on insect pollination, including subtropcial fruit crops such as mangoes, papayas, avocados and litchis, and nut trees such as macadamia, cashews and almonds. These crops are likely to benefit from wild colonies of bees occurring in untransformed vegetation around the tree crops or gardens, saving on active pollination costs incurred by hiring of bee hives or dusting. In addition, domesticated bees kept by farmers for own purposes, for rental to other farmers and for honey production are at least partly dependent upon naturally-occurring vegetation as a source of forage, especially during winter. The number and location of these beehives is however, unknown.

Most rural households mainly grow their own maize, dry beans and sweet potato which provide the majority of their home-grown food (Institute of Natural Resources 2004). While none of these crops require pollination there are certain households that grow their own fruit trees and have small garden crops which benefit from the pollination service provided by natural pollinators. These crops and fruits only make up a small proportion of the home-grown produce.

While we cannot account for the service provided to individual households, we assume that it is small. However, within the EMA there are just over 1000 ha of known commercial fruit tree plantations and commercial market gardens (eThekwini GIS department). We can assume that these areas do benefit from pollination services from natural pollinators, or rely on nearby natural vegetation as an alternative food source for domesticated honeybee pollinators. The distance honey bees travel to collect pollen will be dependent upon a number of factors including season, habitat complexity and colony size (Abou-Shaara 2014). Distance recorded for honey bees foraging in lucerne fields in the USA ranged from under 50 m to almost 6 km (Hagler et al. 2011). While there is no information on movements of honey bees in the EMA, we can assume that there is some demand for pollination service by farmers within 2 km of their farms.

The total value of the pollination service to the fruit trees and commercial market gardens was estimated based on the number of hives required per hectare and the replacement cost of hiring beehives in South Africa (R306; Allsopp et al. 2008). The value of the pollination service was mapped by distributing the total value across the natural habitats within 2 km distance from fruit tree plots and commercial garden markets based on scores of the ability to provide habitat for bees. We assumed that intact natural habitats were best at delivering this service and degraded habitats were not as effective. The fruit tree crops and market gardens are located in small patches throughout the EMA, however the largest areas requiring pollination services are located predominantly in the outer-west and the northern planning regions, as indicated in green in Figure 4.2. The highest potential pollination value is associated with vegetation patches in a good condition that are surrounding market gardens and tree crops. Coastal and scarp forest and open grassland were estimated to have a value of between R65.00 to R90.00 per ha. Thicket and woodland areas were estimated to have a higher value at R130.00 per ha. The total cost of replacing the pollination service to 1144 ha of fruit and garden crops would be just over R1 million per year assuming a conservative estimate of 3 beehives required per hectare.

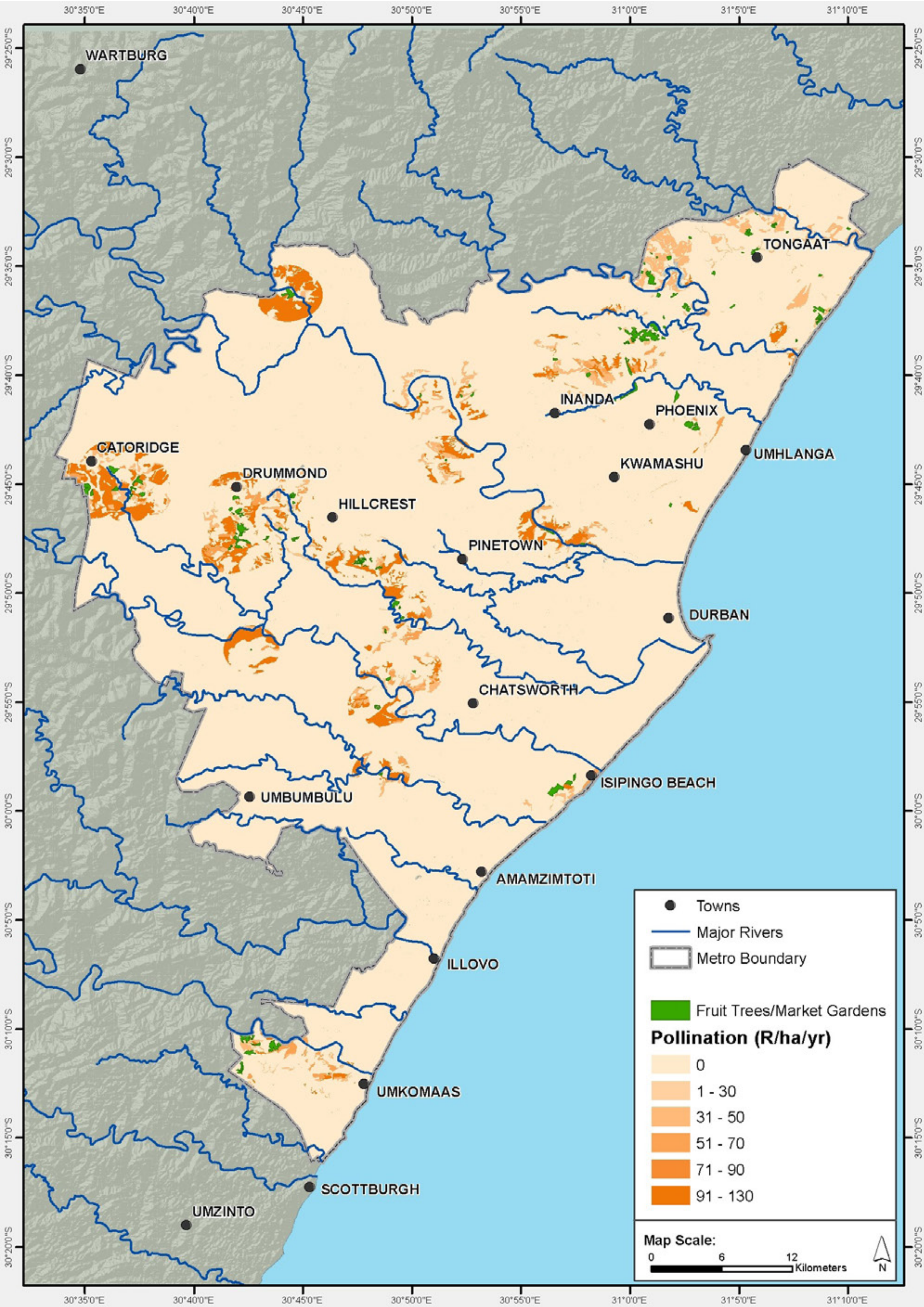

Figure 4.2 The location of market gardens and fruit tree crops and the associated pollination value (R/ha/y)

4.5 Flow regulation

The combination of weather-related (e.g. rainfall intensity, extent and duration) and geophysical (e.g. catchment size, geomorphology, soil and land use) characteristics are the main factors that influence flooding (Kareiva et al. 2011). Natural systems such as wetlands and rivers or ecosystems with deep permeable soils can regulate flows through the landscape by slowing flows by means of storage and vegetative resistance and facilitating infiltration into soils. In this way these systems ameliorate the potential impacts of flood events by reducing the flood peaks and lengthening the flood period at a lower level, reducing bank and streambed erosion (Vellidis et al. 2003), as well as reducing the risk of damage caused by flooding of downstream areas. The landscape capacity for infiltration of rainfall also contributes to groundwater supply and/or dry season surface flows in areas downstream. Dry-season flows are critical to aquatic ecosystem health, as well as to rural populations that are directly reliant on rivers or springs for agriculture, domestic use and livestock watering. The key factors influencing storm peak mitigation are canopy interception, soil infiltration, soil water storage and location in the landscape.

Ecosystems, such as wetlands, floodplains and forests, affect the water balance within a river catchment through interception, evaporation and infiltration (Nedkov & Burkhard 2012). Interception depends on the structure of the land and vegetation above ground (i.e. land cover) and infiltration is strongly influenced by soil properties (Brauman et al. 2007, Nedkov & Burkhard 2012). Surface runoff, which is the main factor for flood formation, is also strongly influenced by other abiotic factors such as topography. Hydrologic ecosystem services can have preventive or mitigating functions (Nedkov & Burkhard 2012). Certain land cover, such as forests and deep permeable soils, are able to redirect or absorb incoming water and rainfall ultimately reducing surface runoff and the amount of water entering river systems. Other ecosystems, such as floodplains and wetlands, provide storm peak mitigation services (Nedkov & Burkhard 2012). These ecosystems provide retention space for any excess water, thereby slowing flows and reducing the impact and power of the flood. Therefore the conversion of forests and wetlands into agricultural or developed land increases the amount of hardened surface thereby increasing the volume of runoff and flooding associated with storm events (Kareiva et al. 2011). This tends to be valid for medium and small return period storm events as vegetation captures water as it flows through the landscape through canopy interception and enhanced infiltration. However, vegetation has limited ability to mitigate flooding associated with large return period storm events because enhanced soil infiltration only captures a small fraction of total precipitation depth for such storm events (Kareiva et al. 2011).

Hydrological models can be used to predict the magnitude of particular floods and to quantify the link between changes in land use and land cover, and flood risk (Kareiva et al. 2011). Using this approach the severity of flooding in terms of water volumes and flow rates, and corresponding damages from the storm event can be estimated. The hydrological model provides the opportunity to define the capacities of different land cover types to supply flood regulation in the EMA. High rainfall events and localised flooding in the EMA has in the past caused damage to infrastructure and property as well as resulted in the loss of life. Large quantities of solid waste and refuse in rivers and stormwater pipes exacerbate the flooding problem in the EMA. Stormwater pipes become overloaded and culverts and grates become blocked. As a result, water backs up rapidly, overtopping barriers and bursting river banks, inundating adjacent properties and roads.

The flood attenuation service can be valued using the lower of either flood damages avoided the avoided costs of replacing the natural systems with alternative flood mitigation options. The avoided damage costs are the extra costs that would be incurred in the form of incremental losses from increased flooding if the natural ecosystems were transformed and also includes the opportunity cost of having to increase setback lines in greenfields areas. The replacement cost method involves estimating the costs of infrastructure that would be required to provide the same level of flood mitigation as the natural systems. In the urban context, as more land becomes transformed, cities such as Durban tend to respond to the resultant increased flood risk by implementing engineering solutions such as changes to the stormwater infrastructure. Indeed, the city is already on a path to increasing the capacity of its infrastructure in preparation for anticipated increases in the size of storm events as a result of climate change (Schulze et al. 2010). Therefore a replacement cost approach was used.

For this study, a hydrological model was set up for the entire catchment area of the eThekwini Municipality using the PC-SWMM software (see Box 4.1). This model was set up to run design flood events in order to determine the influence of natural vegetation areas on flood hydrographs at strategic points relating to the location of existing flood conveyance infrastructure. The flood hydrographs generated under current conditions were compared with what they would be if the natural systems were transformed to urban land use. This provides an indication of the impacts of loss of natural areas on flooding and the difference can be construed as an estimate of the flood attenuation benefit obtained by retaining the natural systems.

Box 4.1 Summary of the flood modelling method (details in Appendix 2)

The full eThekwini catchment system was modelled using the US-EPA SWMM5 hydrology and hydraulics engine, interfaced by the PC-SWMM software. The calibration methodology adopted focused heavily on reducing the uncertainty during model set up.

GIS subcatchment data available for this project from the eThekwini Municipality (EM) flood studies were in the order of 1 km2 and larger. The subcatchments were further discretised into smaller subcatchments, in the order of 0.2 km2, within the eThekwini Municipal Area (EMA). For the region outside of EMA, Shuttle Radar Topography Mission (SRTM – 30 x 30m cell size resolution) data were acquired and special analysis tools were used to discretise the model into 0.5 to 1 km2 sized subcatchments, with larger subcatchments closer to the source areas (Drakensberg). A spatial analysis tool was then used to process the flow paths, watershed boundaries, and river centre lines. The outlet points for the model were then identified and selected; i.e. dams, estuaries and stormwater infrastructure.

EM flood models, based on geometric HecRAS files, were imported into the PC-SWMM model. These datasets account for approximately 30% of the EMA and contain limited stormwater infrastructure (e.g. culverts, bridges). The stormwater network shapefile for the EMA was incomplete and contained numerous errors and inconsistencies. These networks were amended where possible, however due to the extent of the required revisions, a more detailed stormwater network was only included in the U60F quaternary catchment. This quaternary catchment encompasses the main developed part of the city, and is also the study area for the green urban development scenario analysis, which is in an accompanying report.

Available current GIS landuse files (e.g. zoning files, D'MOSS) were collated and reviewed. These files were concatenated into one consistent landuse polygon shapefile and the landuse classifications were reviewed and summarised into a common set of landuse conventions. The resulting shapefile was 'groundtruthed' using aerial imagery for the whole of the EMA. The Southern African National Land Cover dataset (2013/14) was used for the catchments outside of the EMA. The 72 different landuse descriptions were summarised into a more manageable list of landuse categories consistent with those used within the EMA.

A number of input parameters are required for SWMM5. These include hydraulic parameters, soil infiltration properties, rainfall and water quality parameters. The determination of the catchment characteristics was estimated using a spatial analyst tool for zonal statistics. Raster files were generated to represent the information required for the hydraulic and hydrological models, with reference to each subcatchment. The most significant input hydraulic parameter is the percentage of impervious area (Imperv. %). The hydraulic parameters were assigned to each landuse classification based on literature. The largest proportion of rainfall losses over pervious areas generally occur due to soil infiltration. The Green-Ampt method was adopted for this study. This method provides a soil memory as opposed to a broad brush coefficient approach. Three user-specified soil parameters were used; i.e. capillary suction head, saturated hydraulic conductivity, and the maximum available moisture deficit. Average daily abstractions and return flows/discharges were added as point sources at the appropriate junctions. There are a number of large dams in the EMA. For simplicity, the model was split by routing all the flows entering the dam to an outfall. A new flowpath was created downstream of the dam.

A user-defined hyetograph was used as the precipitation input into the model. The hyetograph was created using the total daily mean-areal precipitation depths derived by Smithers & Schulze (2000) for a 24-hour design storm. The temporal distribution was derived using a synthetic SCS Type II distribution for 2-, 5-, 10- and 20-year return periods.

The final SWMM model of the full EMA comprised about 30 000 subcatchments. The eThekwini catchment system was divided into 3 separate models, representing the northern, central and southern catchments to reduce simulation running times (Figure 4.3).

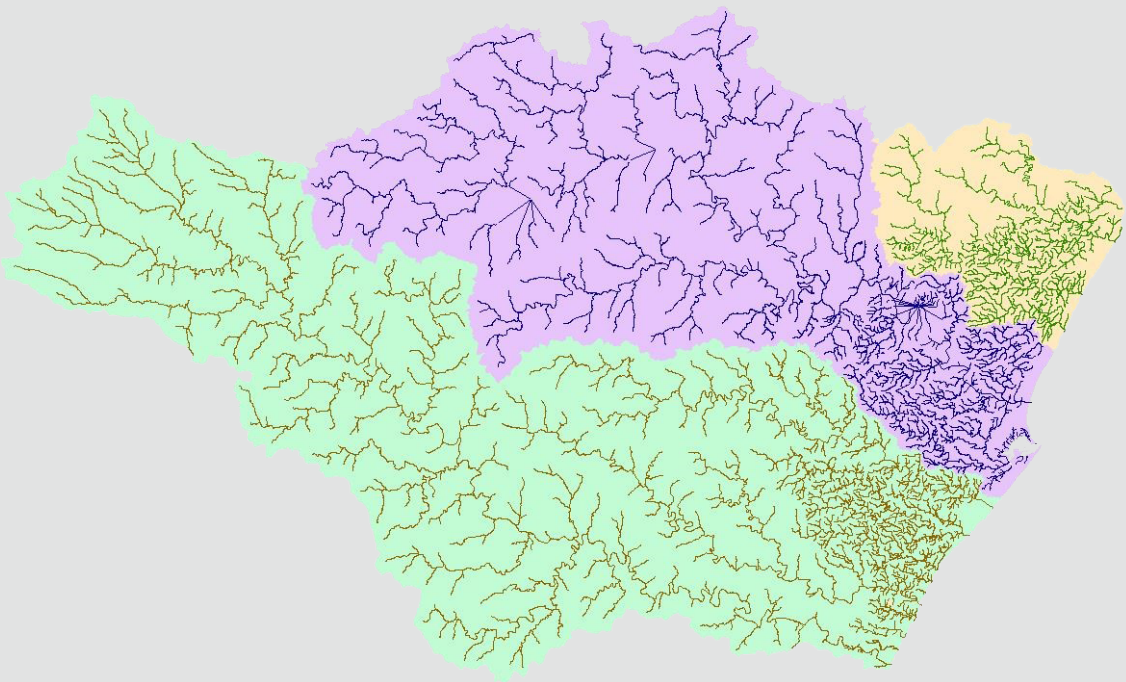

Figure 4.3 The full eThekwini catchments showing flow paths

The additional flood volumes that would occur under different return period flood events (e.g. 1:10 years), would require larger drains, culverts, etc., depending on the size of the event they are designed to deal with. Thus a second model was developed in order to estimate the capital costs of the structures required under the present versus the without-vegetation scenarios (see Box 4.2). The difference, together with associated differences in maintenance costs, is the total life-cycle cost avoided, which can be converted to a net present value which is the value of the service.

Box 4.2 Summary of the method used to estimate engineering cost savings (details in Appendix 3)

An analysis was undertaken to determine the difference in the replacement cost of stormwater infrastructure (including both conveyance and storage) between the existing stormwater infrastructure in the EMA and infrastructure that would be designed to different specifications depending on the amount of natural vegetation within the EMA.

The adopted methodology for this analysis focused on estimating the cost difference of the infrastructure with and without natural/undeveloped areas in the EMA. The relationship between cost and flow for the status quo was established and used to estimate the cost of infrastructure based on changes caused to the flow as a result of having natural areas within the EMA developed into the average land use, i.e. what happens to the flows if the current D'MOSS is replaced with the average land use type within that catchment?

The methodology used to determine stormwater infrastructure engineering costs is outlined as follows:

1. Identify all stormwater infrastructure within the EMA
2. Divide the infrastructure into four major categories (bridges, canals, culverts and pipes)
3. Determine the dimensions of all infrastructure in the EMA
4. Estimate the costs of the existing infrastructure based on these dimensions
5. Assign rainfall design return periods to each category of infrastructure
6. Calculate the maximum open channel flow from the Mannings equation (i.e. the threshold flow)
7. Estimate a scaling relationship between infrastructure dimensions and flow using theoretical uniform flows
8. Simulate the design rainfall return periods and estimate the maximum design flows for each scenario (status quo versus average land use)
9. Use the maximum flows, the existing infrastructure dimensions and the threshold flows to scale the existing infrastructure to required infrastructure dimensions under the average land use scenario
10. Use the new infrastructure dimensions to estimate the cost of the scaled infrastructure
11. Compare the cost of the existing infrastructure to the cost of the scenario infrastructure

Because much of the flood conveyance infrastructure is overdesigned for various reasons including the problems of blockages by litter, the estimation initially yielded a small cost to increase the size of the structures to deal with the difference in flows. Since this is clearly downward biased, a correction was then applied to adjust for this overdesign and produce a more comparable estimate from which to derive the realistic difference in value.

The savings in the capital cost requirements for flood conveyance were estimated to be in the range of R63 – R338 million (Table 4.5, Figure 4.4). This represents a 0.7% - 3.5% capital cost saving in stormwater infrastructure. Including an estimated 6% of capital costs as an annual repair and maintenance cost (eThekwini Municipality 2015), this suggests that the flood attenuation service provided by natural systems in the EMA has a net present value in the order of R107 – R571 million (average R339 million; Table 4.5). We consider the upper bound value to be the closest approximation of the value of the service. The highest per hectare values associated with D'MOSS are located in catchment U20L and U60F, catchments that are situated above the built up areas of Durban city centre and Durban North (Figure 4.4). These D'MOSS areas in upper catchment areas therefore provide a significant flood attenuation service.

Table 4.5 Lower and upper bound flood attenuation values (R million) for each quaternary in the EMA. A zero value indicates that there is no stormwater infrastructure within that catchment.

Quaternary Catchment	Lower bound			Upper bound		
	Capital cost savings	Maintenance Cost (NPV 20 yrs, 6%)	Flood attenuation value (R million)	Capital cost savings	Maintenance Cost (NPV 20 yrs, 6%)	Flood attenuation value (R million)
U10M	-	-	-	-	-	-
U20J	-	-	-	0.1	0.1	0.2
U20K	0.1	0.1	0.2	0.1	0.1	0.2
U20L	0.3	0.2	0.4	106.2	73.1	179.3
U20M	18.0	12.4	30.4	25.7	17.7	43.4
U30B	20.0	13.8	33.8	31.7	21.8	53.6
U30D	2.3	1.6	3.9	77.7	53.5	131.2
U60C	3.4	2.4	5.8	3.5	2.4	5.8
U60D	2.1	1.4	3.5	3.5	2.4	5.9
U60E	0.0	0.0	0.1	0.4	0.3	0.7
U60F	13.9	9.5	23.4	85.3	58.7	144.0
U70B	-	-	-	-	-	-
U70C	-	-	-	-	-	-
U70D	2.1	1.4	3.5	2.1	1.5	3.6
U70E	0.0	0.0	0.0	0.1	0.1	0.2
U70F	1.2	0.8	2.0	1.7	1.2	2.9
Total	**63.3**	**43.6**	**106.9**	**338.1**	**232.7**	**570.7**

The average estimated flood attenuation value for natural vegetation in each catchment was mapped to the green open space areas within that catchment using an estimate of the relative contribution of different land parcels to flood attenuation modelled using InVEST modelling software (Glenday 2012). This provided the relative flood attenuation score given to each grid cell within the EMA based on rainfall, soil and landcover. The value per pixel was then determined for all green open space areas (based on the latest GIS data of D'MOSS), total flood retention value for each catchment, the retention score given to the pixel and the sum of all pixel flood retention scores. The value per pixel was then divided by the area of the pixel to arrive at a flood retention value per hectare estimate for all green open space areas in the EMA.

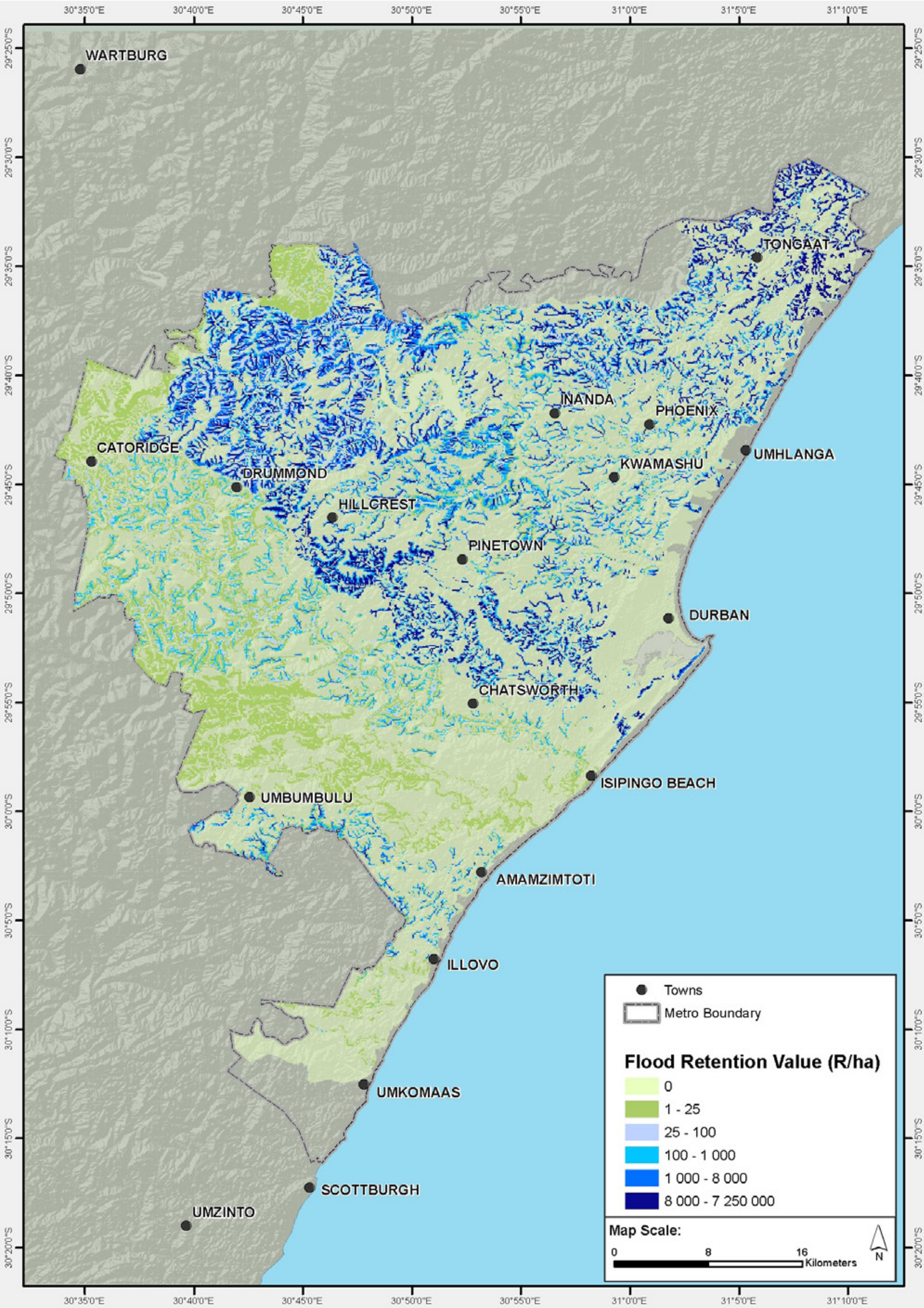

Figure 4.4 Flood attenuation value associated with natural systems (D'MOSS) (NPV, R/ha) in the EMA

4.6 Sediment retention

Human activities within the landscape can lead to increased soil erosion and the introduction of nutrients into river systems from agricultural activities and human wastes. Agricultural expansion, encroachment into natural wetlands and the removal of natural vegetation result in elevated levels of erosion and subsequent increases in sediment loads being carried downstream. The total sediment load being transported in rivers is made up of bed load, suspended load and dissolved load. The bed load is the portion that is transported along the river bed, is coarse and generally moves at velocities slower than the flow. The suspended load is particulate sediment that is held in the water column, and is made up of smaller particles such as clay and fine silt. The dissolved sediment load is the material that is chemically carried in the water. When flow speeds drop—when rivers enter dams, lakes, wetlands or estuaries—the loads that are carried tend to drop out of suspension and accumulate, with the smallest particles taking longest to settle out. In this section, we focus on the problem of sedimentation of man-made structures and harbours. Elevated loads of suspended sediments also contribute to water quality problems, which are addressed in Section 4.7.

The extent to which sediments end up in river systems is determined by a number of factors including soils, rainfall patterns (amount and intensity), slope and the type and amount of vegetative cover. Vegetative cover prevents erosion by stabilizing soil and by intercepting rainfall, thereby reducing its erosivity (De Groot et al. 2002). This is particularly valuable where soils are highly erodible. Vegetated areas, especially wetlands, may also capture the sediments that are eroded from agricultural and degraded lands and transported in surface flows, preventing them from entering streams and rivers (Blumenfeld et al. 2009, Conte et al. 2011). This protects downstream areas from the impacts of sedimentation, which can include impacts on water storage capacity, hydropower generation and navigability of rivers (Pimentel et al. 1995). While some level of sedimentation of dams is expected under natural conditions and planned for, elevated catchment erosion either incurs dredging costs or shortens the projected lifespan of dams and related infrastructure. Globally, anthropogenic sedimentation has been estimated to account for about 37% of the annual costs of dams (i.e. $21 billion) in terms of replacement costs (Basson et al. 2009). In urban contexts, elevated sediment loads also have to be removed from sewerage systems, storm water drainage systems and harbours.

In the EMA, natural sediment transport from catchments is the main source of beach sand. Most of the sand that is supplied to the coast comes from bed load in the river, with very little sand contributed by the suspended load (CSIR 2008). However, both dams and sand mining have all but cut off the supply of sand to the coast, with dams trapping almost 100% of coarse sediments that flow into them (CSIR 2008). This is not a problem that can be solved by the conservation of landscapes in the EMA, but can only be solved by expensive engineering solutions such as off-channel dams, and the control or elimination of sand mining. Notwithstanding their contribution to beach erosion problems, the fact that the dams trap sediments is also costly, and this cost is elevated when sediment yields from the catchment are elevated by human activities. Here, ecosystem services do play a role in reducing the potential extent of these costs due to increasing human activity in their catchments. In the EMA, sedimentation problems are mainly associated with the water supply dams (Box 4.3) and Durban Harbour. Because of the steep gradients of much of the EMA, sedimentation of drainage networks is fairly limited (Geoff Tooley, pers. comm.).

Box 4.3 The main water supply dams of the EMA

There are three large water supply dams in th EMA that have part of their catchment areas falling within the EMA, and that therefore potentially benefit from sediment reduction services delivered within the EMA as well as in the rest of their catchment areas1.

Inanda Dam, located on the uMngeni River, is the largest of three dams and supplies water to Wiggins WTW the second largest treatment works in the EMA. It is the largest of the three water supply dams. Inanda Dam is located 25 km upstream of the uMngeni Estuary and is known to cut off the main source of coarse material to the estuary (Cooper 1993), trapping 99.6% of coarse sediments (CSIR 2008).

Hazelmere Dam is located on the uMdloti River and supplies water to Hazelmere WTW on the north coast and also supplies water for agricultural irrigation. CSIR (2008) found that present sediment yields in this catchment are much lower than the historic levels, the result of significant land use changes (less subsistence agriculture and more natural vegetation).

Nungwane Dam is the smallest of the three dams and supplies water to the Amanzimtoti WTW on the south coast. While the Nungwane Dam has a sediment trapping efficiency of 99.1%, the dam is situated on a tributary of the Lovu River and thus does not trap the main river sediment load moving to the coast.

Details relating to the three water supply dams located within the EMA

Water Supply Dam	Inanda	Hazelmere	Nungwane
River	uMngeni	uMdloti	Nungwane
Year completed	1989	1977	1978
Associated WTW	Wiggins	Hazelmere	Amanzimtoti
Total catchment area (km^2)	1547	377	58
Sediment yield in catchment ($t/km^2/y$)	314	381*	340*
Initial dam capacity (million m^3)	259	23.9	2.4
Current dam capacity[2] (million m^3)	252	17.9	2.24
Coarse sediment trapping efficiency* (%)	99.6	98.7	99.1
Capital Replacement Cost (2008, R million)	769.4	473.4	?

Source: * CSIR 2008; (1) (2) Umgeni water website

Figure 4.5 Inanda, Hazelmere and Nungwane Dams are located within the EMA (Source: Umgeni Water)

[1] Note: Two other dams, the Shongweni Dam (Mlazi River) and Dudley Pringle Dam (Wewe River) were not included in this analysis for the following reasons: (1) the Shongweni Dam (capacity of 3.8 million m3) has been decommissioned as far as water supply is concerned. It is used only for recreational purposes; and (2) the Dudley Pringle Dam (capacity of 2.3 million m3) is owned by Tongaat Hulett and supplies water to Maidstone Sugar Mill. It is also used for irrigation purposes and the eThekwini Municipality have the rights to extract up to 15 Ml/day to supply Tongaat WTW. However, the dam is located on the northern border of the EMA with almost all of the catchment falling outside of the EMA.

A model was set up in PC-SWMM software to simulate the hydrology and sediment transport for the catchment area of the whole municipality, and to estimate the extent to which natural vegetation prevented sediments from entering the main reservoirs and estuaries, by comparing rates of sedimentation with and without natural vegetation (Box 4.4).

Box 4.4 Summary of sediment modelling approach (see Appendix 4 for details).

Annual sediment loads were estimated by simulating the total suspended sediment load (TSS) using the PC-SWMM model described in Appendix 2. TSS loads were simulated for one year from August 2013 to August 2014. The pollutant washoff from a given landuse during periods of wet weather was characterized in the model by using a user defined Event Mean Concentration (EMC). The EMCs were derived from literature and applied to the different landuse categories. Model subcatchment parameters were derived by area weighting the various land use parcels within each subcatchment. The modelled runoff flows were coupled with EMC values to estimate the concentration and total load of TSS at different points in the study area.

The percentage contribution of bed load and suspended sediments to the total sediment load is different for each catchment. For this study suspended sediment loads were multiplied by a factor of 1.25 in order to account for bed load. This is the factor generally applied in South Africa (Msadala et al. 2010, after Rooseboom 1992).

By comparing the modelled sediment outputs per catchment under current land cover versus fully transformed land use, it was possible to estimate the difference made by natural vegetation to the sediment loads transported to dams and estuaries. Two scenarios were used to estimate the sediment retention service provided by existing natural vegetation in the EMA. The first scenario involved removing the trapping capacity of natural vegetation (a hypothetical construct) and the second involved replacing natural vegetation with dense rural settlement as a likely alternative land use. These two scenarios provided lower and upper bound estimates of the magnitude of the service. A detailed description of the model is provided in Appendix 4.

The costs of sedimentation of dams could be estimated either as the replacement cost of lost storage capacity (e.g. through raising the dam wall or constructing a substitute dam at a new site to make up the reduction in capacity), or as the cost of dredging to remove the accumulated sediment. For dams, we estimated the value of the service in terms of dam construction costs (being the lower cost option), based on modelled cumulative storage loss over 20 years (Box 4.5). For Durban Harbour, we used the avoided dredging cost, under the assumption that these would be lower than the damage costs avoided as a result of ecosystem degradation (Box 4.6). For the rest of the estuaries, the impacts of changes in TSS loads were considered together with water quality (see Section 4.7).

The loss of vegetation cover from their catchments would lead to a significant increase in the rate of sedimentation of all three of the main water supply dams (Figure 4.6). The greatest impacts would be felt by Hazelmere Dam, which has a large area of natural vegetation in its catchment. The replacement of these natural areas with human settlements could result in a nine-fold increase in sediments entering the dam (Figure 4.6, Table 4.6). The total annual replacement cost associated with the loss in dam capacity as a result of sedimentation is estimated to be between R1.1 million and R2.9 million (average R1.97 million; Table 4.6). Over a 20 year period from 2015 and using a discount rate of 6% this equates to a net present value of between R12.25 million and R33.03 milllion (average R22.77 million).

Box 4.5 Estimation of costs avoided for dams

The sedimentation rate over a dam's lifetime can be projected from a measurement at some point in time, using the Vt/V50 relationship developed by Rooseboom (1975, see also WRC 1992):

$$V_{50} = V_t \Big/ \left(0.376 \ln\left(\frac{t}{3.5}\right)\right)$$

Where V50 = sediment volume after 50 years, Vt = sediment volume measured after t years, and t = period in years. Sedimentation of the three dams was modelled using data on average sediment yields in the catchment, starting capacity and current (2015) capacity (Box 4.3). The percentage change in rate of sedimentation was taken from the sediment modelling study. The actual rate of sedimentation estimated in the sediment modelling study was lower than the rate estimated based on the above method, but was considered to be the less reliable estimate of actual rates.

The volume of sediment was estimated from mass using a density of 1.35 t/m3 (Rooseboom 1992, Haarhoff & Cassa 2009). The loss of capacity over a 20 year period was estimated, and costed in terms of the cost of replacing the equivalent capacity, based on the capital replacement costs of the dams.

Box 4.6 Estimation of costs avoided for dredging of Durban harbour

The avoided sedimentation of Durban harbour was taken as the difference in annual sediment input between the modelled scenarios. The avoided costs were estimated using dredging data provided by Transnet for Durban Harbour for the period 1 April 2015 – 31 March 2016. Maintenance dredging involves the removal of sediments from channels, basins and berths within the harbour. Dredging of channels and basins costs R85 per m3 on average and dredging of berths costs R636 per m3. A total of just under 182 000 m3 of sediment was dredged from the harbour over the period 2015/16, at an overall average cost of R229 per m3 (Transnet NPA). However, most of the sediment removed from the harbour through maintenance dredging is not derived from river inputs but is from exisiting estuarine sediments that are shifted by the movement of large ships through the harbour (Transnet NPA). The "silt canal" at the top end of the estuary is not dredged on a regular basis and it is estimated that less than 5% of the annual volume of dredged sediment is of fluvial origin (Clive Greyling, Transnet NPA pers. comm.). This corresponds to the modelled status quo TSS load which represents 2.6% of the annual volume of dredged sediment.

The annual TSS loads generated under current conditions were compared with what they would be if the natural systems within the catchment were removed or transformed to a different land use, such as rural dense settlement. The annual TSS loads were converted to volume (1.35 t/m3) and multiplied by the overall average dredging cost, with the difference in costs between the scenarios representing the costs avoided for dredging of Durban harbour.

It was estimated that the annual TSS load into Durban Harbour increased by 195% compared to the current load when vegetation in the Umhlatuzana-Umbilo catchment was removed (lower bound) and by 206% when the vegetation in the catchment was replaced with dense rural informal settlement (upper bound, Table 4.7). This results in dredging costs avoided of between R1.03 million and R1.15 million (average R1.1 million) per year.

The overall net present value of the sediment retention service was estimated to be in the order of R35.17 million. The portion of the value pertaining to each dam and the harbour was mapped to the green open space areas within the relevant catchments using an estimate of the relative contribution of different land parcels to sediment retention modelled using InVEST modelling software (Glenday 2012). This provided the relative sediment retention score given to each grid cell within the EMA based on rainfall, soil and landcover. The value per pixel was then determined for all green open space areas (based on the latest GIS data of D'MOSS), total sediment retention value for each catchment, the retention score given to the pixel and the sum of all pixel retention scores. The value per pixel was then divided by the area of the pixel to arrive at a sediment retention value per hectare estimate for all green open space areas in each catchment.

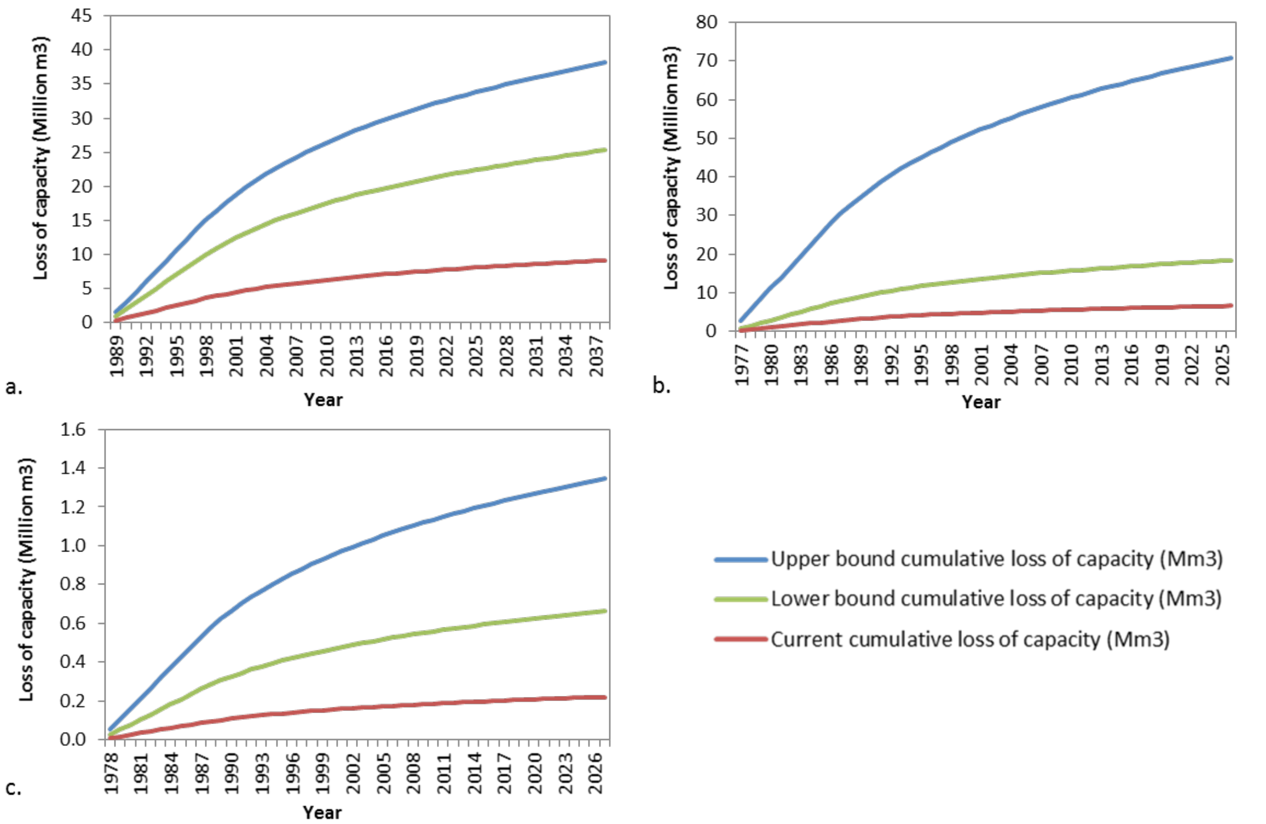

Figure 4.6 The current, lower bound and upper bound cumulative loss of capacity (Mm3) over 50 years for (a.) Inanda Dam, (b.) Hazelmere Dam and (c.) Nungwane Dam

Table 4.6 Lower and upper bound flood attenuation values (R million) for each quaternary in the EMA. A zero value indicates that there is no stormwater infrastructure within that catchment.

Dam	Replacement cost (R millions per year)		NPV 20y from 2015, 6% (R millions)	
	without vegetation (lower bound)	with settlement (upper bound)	without vegetation (lower bound)	with settlement (upper bound)
Inanda	0.79	1.42	9.09	16.31
Hazelmere	0.26	1.42	3.01	16.33
Nungwane	0.01	0.03	0.15	0.38
TOTAL	**1.07**	**2.88**	**12.25**	**33.02**

Table 4.7 Estimated maintenance dredging costs avoided due to the sediment retention function of natural vegetation in the Durban Harbour catchment.

Durban Harbour	Average dredging cost (R/m^3)	Change in annual TSS load (m^3)	% change in annual TSS load	Annual dredging costs avoided (R millions)	NPV
Lower bound	229	4 511	195%	1.033	11.85
Upper bound	229	5 029	206%	1.152	13.21

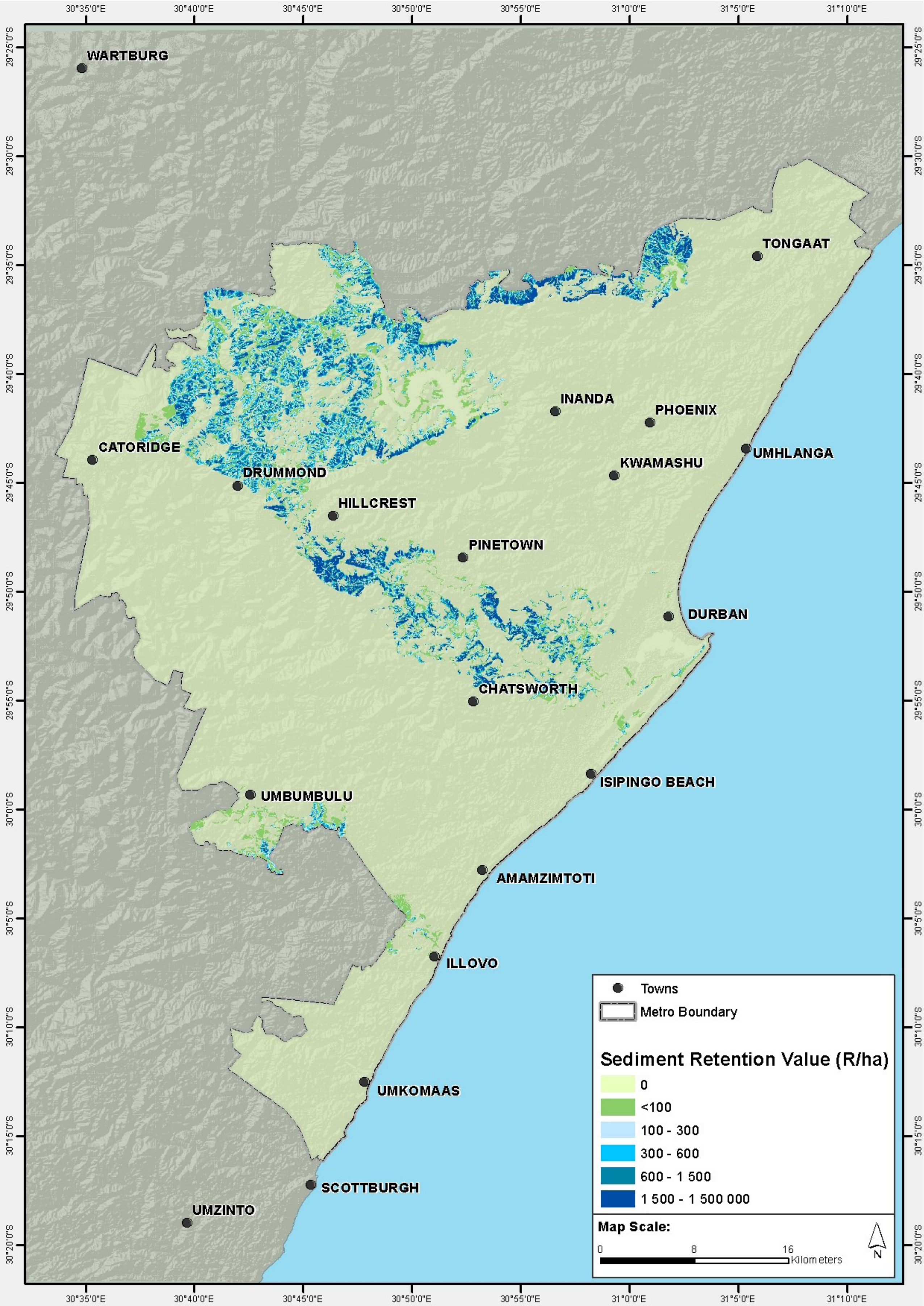

Figure 4.7 Sediment retention value associated with natural systems (D'MOSS) (NPV, R/ha) in the EMA

4.7 Water quality amelioration

The introduction of nutrients into the landscape (anthropogenic eutrophication) can lead to reduced water quality and the eutrophication of freshwater and marine ecosystems. This reduces their capacity to supply ecosystem services as well as increasing water treatment costs (Graham 2004, Rangeti 2014). Nutrient enrichment of water resources often occurs in highly populated urban areas where agricultural activities, use of fertilizers, untreated sewage, organic wastes and water-borne sewage systems lead to increased nutrient loads in surface waters.

Where excessive nutrients end up in water supply reservoirs, the resultant algal growth leads to increased water treatment costs. A number of studies have analysed the effect of water quality variables on water treatment costs in South Africa (e.g. Dennison & Lynne 1997, Graham 2004, Friedrich et al. 2009, Gebremedhin 2009, Graham et al. 2012, Rangeti 2014) as well as globally (e.g. Dearmont et al. 1998, Nkonya et al. 2008, Telles et al. 2013, McDonald & Shemie 2014, TNC 2015).

In the study area, Graham (2004) showed that the costs of water treatment for four WTWs operated by Umgeni Water increased as a result of increases in turbidity, aluminium, iron, suspended solids, nitrates, total organic carbon (TOC), total dissolved solids, silicon, coliform numbers, potassium and algae in their respective reservoirs. Rangeti (2014) also found that algae, turbidity and TOC in the Inanda and Nagle Dams were the key drivers in chemical dosage and chemical costs in treating potable water at Durban Heights and Wiggins WTWs. However, none of these studies or studies from further afield have developed models to relate water treatment costs to the pollutant loads entering the reservoirs (which can be related to land use and anthropogenic inputs) and only one (Vincent et al. 2015) has related treatment costs directly to the state of the catchment. These kinds of relationships need to be estimated in order to estimate the value of water quality amelioration services.

The anthropogenic deterioration of water quality also has a negative impact on the health of aquatic ecosystems and their capacity to deliver ecosystem services. For example, increases in nutrient and suspended sediment loads entering estuaries lead to impacts on fish stocks, estuarine fishery values and the export of fish to marine fisheries. Thus water quality amerlioration by natural areas can also play an important role as a supporting service.

Water quality amelioration is the removal of some of the excess nutrients and sediments that are generated through anthropogenic processes in the landscape and transported in surface water runoff and/or groundwater systems. There are a number of different processes through which natural systems remove pollutants from surface and sub-surface flows (Figure 4.9). Nitrogen

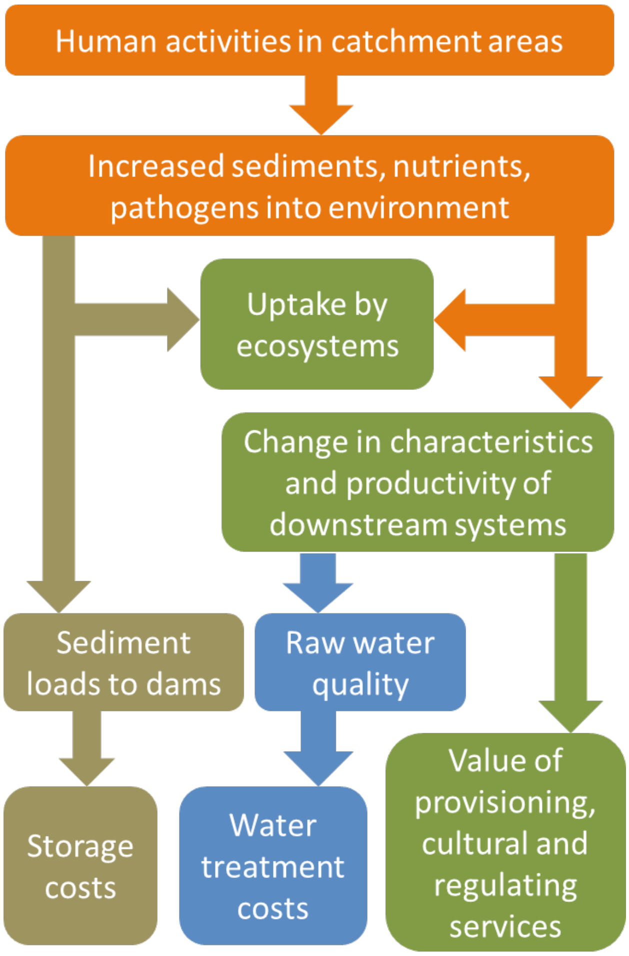

Figure 4.8 Schematic diagramme of the consequences of anthropogenic effect on water quality and their amelioration by natual systems: (Source: Author)

removal is mainly through denitrification and also to some extent by plant uptake (Hill 2000). Nutrients that are introduced in dissolved form can be taken up directly by plants and incorporated into plant tissue as they grow. Most of the phosphorous that is transported by flows is attached to sediment and settles out, where it can remain inactive (Brinson 2000). However, if sediments that settle in aquatic systems are stirred up again then some of this phosphorous can go back into solution and become available for use by plants. Phosphorus is usually naturally limiting (in short supply) in freshwater systems, whereas nitrogen is typically limiting in marine systems and estuaries. Therefore plant uptake uses up different nutrients in different systems. The uptake of nutrients will continue as long as there is room for further plant growth (in terms of space, oxygen or plant size limits), after which the system will reach some kind of equilibrium in which the uptake is balanced by the senescence, death and rotting of plant material which reintroduces nutrients into the water column (remineralisation). At this point there would be no further net uptake of nutrients by the ecosystem unless

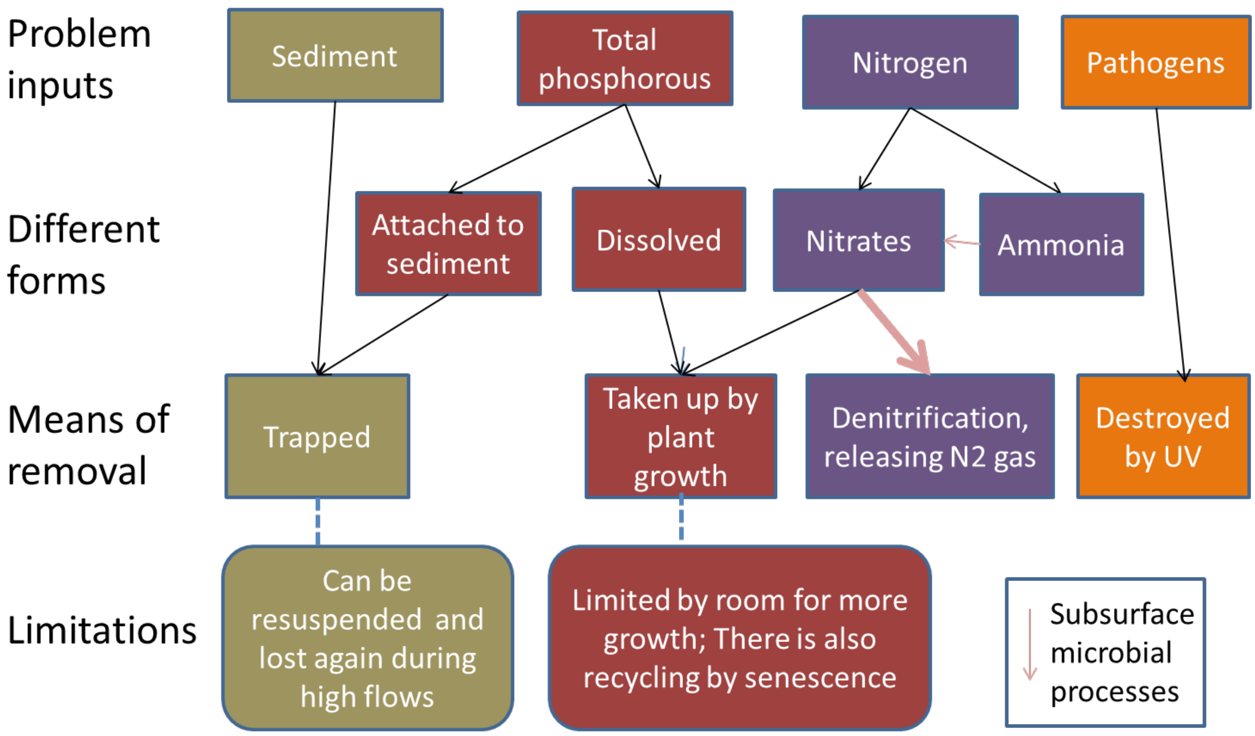

Figure 4.9 Summary of water quality amelioration services by natural systems (Source: Turpie 2015)

nutrients are being exported out of the system (e.g. by harvesting plants or dredging and removal of sediments), or unless there is a natural process of peat formation.

Wetlands are generally regarded as the most efficient natural system for removing pollutants, partly because they have much greater capacity for traping sediments, but forests and other terrestrial vegetation types also have the capacity for water quality amelioration (Asmussen et al. 1979). Terrestrial systems have been shown to improve water quality at a landscape scale (Dixon & Rowlands 2007), and it has also been shown that natural vegetation along streams acts as an important buffer between agricultural landscapes and river systems, removing a high percentage of sediments and nutrients from surface and subsurface flows (Mayer et al. 2007, Liu et al. 2008, Yuan et al. 2009, Zhang et al. 2010, Weller et al. 2011, Sweeney & Newbold 2014).

Water quality amelioration services only have value downstream of where wastes are generated and wherever downstream water and ecosystem services occur that would be impacted by a loss of water quality. Water quality amelioration is thus largely a supporting service of terrestrial and aquatic ecosystems that influences the output of final goods and services from downstream aquatic ecosystems as well as reducing the potential costs of water storage and treatment. Studies that put a monetary value on this service frequently make the assumption that natural systems such as wetlands remove the total pollution input load (e.g. Emerton et al. 1998, Qian & Linfei 2012).

Accurate valuation of this service requires a much better understanding of the removal rates of natural systems or better evidence of its impact on the downstream costs or benefits. This usually requires the use of both biophysical as well as economic analytical and modelling tools (Keeler et al. 2012).

In this study, the impacts of natural open space areas on water quality were estimated using a hydrological model which was set up to estimate the production and transport of total suspended solids (TSS), phosphorus (P) and total inorganic nitrogen (TIN) in the catchments of the EMA. The model was set up to estimate the changes in loads entering dams and estuaries if the retention capacity of natural vegetation was eliminated, or if natural vegetation was replaced with dense human settlement (see Box 4.7). These two scenarios provided the upper and lower bound of the service provided by natural open space areas in physical terms. The value of the service was then estimated in terms of the avoided costs to water treatment works and the avoided loss of estuary value as a result of the eutrophication of these systems.

Water treatment cost savings were estimated for the three water treatment plants based on data supplied by Umgeni Water and the eThekwini Water and Sanitation Department on the Durban Heights WTW and Wiggins WTW and the Nagle and Inanda Dams. Two separate models were developed to relate phosphorous loads entering the water supply dams to the water treatment costs at each of the WTWs (see Box 4.8). While there was detailed data available for the uMngeni River system and associated dams and water treatment plants, data for the Hazelmere Dam (and associated Hazelmere WTW) and Nungwane Dam (and associated aManzimtoti WTW) were not available. The model developed for Nagle Dam and Durban Heights WTW was therefore applied to Hazelmere and Nungwane. Nagle Dam is much smaller in size than Inanda Dam, with the dimensions of the reservoir being more comparable to Hazelmere and Nungwane Dams. The technology and chemicals used to treat water at Durban Heights WTW and at Hazelmere and aManzimtoti WTW are also comparable. The modelled impact of the removal/ replacement of natural habitats on phosphorus loads and water treatment costs was used to estimate the water quality amerlioration value of natural open space areas in the catchment areas of each dam.

Box 4.7 Summary of the hydrological - nutrient modelling methods (detail in Appendix 4)

The impacts of natural open space areas on water quality were estimated using a hydrological model set up in PC-SWMM software for the catchment area of the whole municipality. The model, described in Appendix 4, was set up to estimate the average annual loads of nutrients entering raw water reservoirs of water treatment plants within the EMA.

The EMC for nutrients, TIN and P, were derived from literature and applied to the different landuse categories within the study area. Simulated catchment runoff was coupled with the EMC values to estimate total annual nutrient loads. TIN and P loads were simulated for one year from August 2013 to August 2014 (total annual precipitation of 572 mm for the Durban city area, lower than MAP).

The annual phosphorous loads generated under current conditions were compared with what they would be if the natural systems were removed or transformed to a different land use, such as rural dense settlement. This provides an indication of the impacts of loss of natural areas on nutrient loads entering surface waters and the percentage change can be construed as an estimation of the water quality amelioration benefit obtained by retaining the natural systems.

Box 4.8 Summary of method used to estimate avoided water treatment costs (detail in Appendix 5)

A series of water treatment cost models were used to estimate the water quality amelioration value associated with natural open space in the catchments of water supply dams in the EMA. Water treatment cost data and water quality data were provided for a five year period from 1 July 2010 – 30 June 2015 for the two largest WTW in the EMA; Durban Heights and Wiggins which receive water from Nagle Dam and Inanda Dam on the uMngeni River. Together, these two treatment works supply more than 60% of the potable water in the EMA. Treatment cost data and water quality data were analysed and it was expected that higher nutrient loads, in particular phosphorous, in the uMngeni River would result in increased water treatment costs as a result of increased algal growth and associated changes in water colour and odour.

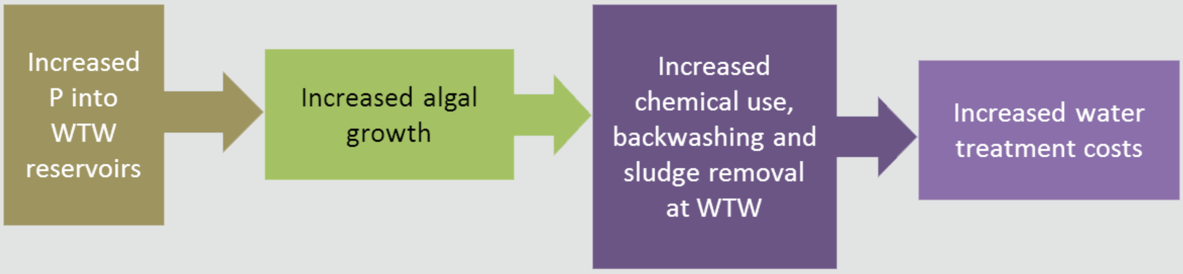

Figure 4.10 Schematic summary of the linkages from phosphorous loads in water supply dams to increased water treatment costs as a result of deteriorating water quality.

The first set of regression models investigated the relationship between treatment costs (R/m3 of treated water) and a range of water quality variables in the water being abstracted from the supply dams. The results from these models indicated that the increase in suspended solids and algal blooms, especially during the summer rainfall months from November through to March, are the main reason for heightened treatment costs. The rising costs associated with these factors are a result of increased usage of coagulants and disinfectants needed to remove suspended sediments and algae, and associated odour and colour issues, during the treatment process. All regression models took the following form:

$$TC_p = f(x_s, x_n, x_e)$$

where TC_w is the water treatment cost associated with treating 1m3 of water and x_n,x_c,x_a are the nutrient, chemical and algal water quality paramters related to TC_w.

The next set of models linked treatment costs to phosphorous loads and other water quality variables such as coliforms, colour, temperature and alkalinity in the water entering the water supply dams. The results revealed that the phosphorous loads in the uMngeni River entering Nagle Dam and Inanda Dam were positively and significantly correlated with water treatment costs at both Durban Heights WTW and Wiggins WTW (see Table A5. 5 and Table A5. 7 in Appendix 5). The model results had a reasonable fit to the actual treatment cost data supplied for Durban Heights WTW and Wiggins WTW.

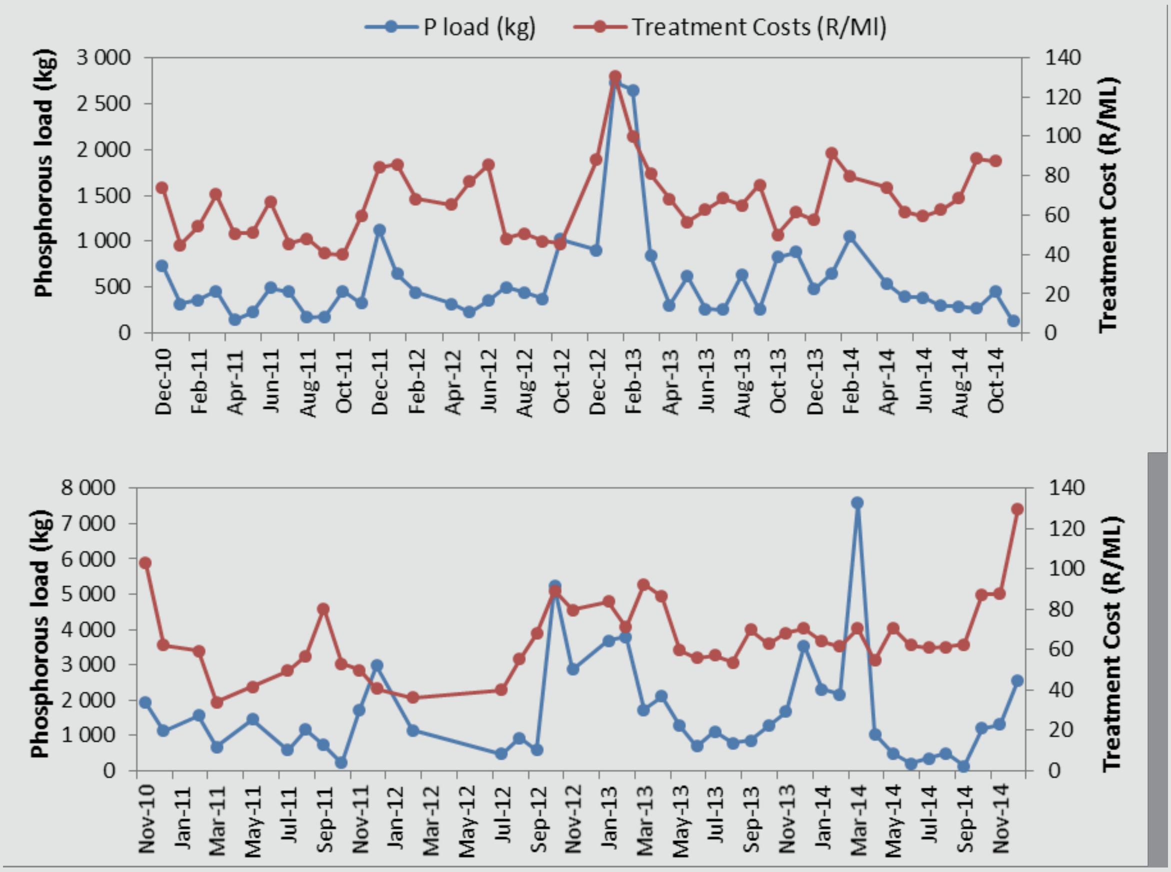

Figure 4.11 Average phosphorous loads (kg) in the uMngeni River above Nagle Dam (top) and Inanda Dam (bottom) and corresponding water treatment costs (R/ML) at Durban Heights WTW and Wiggins WTW.

These water treatment cost models were used to predict the outcome of catchment land-use changes, such as the impact that natural vegetation on reducing nutrient runoff into surface waters. Using a simple scenario approach, comparisons between the status quo and modelled outputs for phosphorous loads into water supply dams can be related to the treatment costs using the above models and overall cost savings can be estimated.

The detailed water treatment cost analysis, methodology and model results can be found in Appendix 5.

A third model was developed to estimate the avoided loss of estuary values as a result of water quality amelioration by natural systems (see Box 4.9). The model was developed based on statistical relationships between nutrient and TSS loads, water quality scores and the status of fish communities described by experts in these fields for the EMA's 16 estuaries, and the nursery values described in Section 4.3. The modelled impact of the removal/replacement of natural habitats on nitrogen and TSS loads, estuary water quality, fish populations and nursery value was used to estimate the water quality amerlioration value of natural open space areas in the catchment areas of each estuary.

Box 4.9 Relationships between increased N and TSS loads, estuary water quality and the status of estuarine fish communities

Anthopogenic increases in nitrogen and TSS have a negative impact on estuarine health and the capacity of estuaries to deliver services such as recreational fishing value and nursery value (Figure 4.12). Estimation of the water quality amelioration service on estuary values required the development of a model to estimate the impacts of changes in N and TSS loads on water quality, and the impacts of changes of water quality on fish populations.

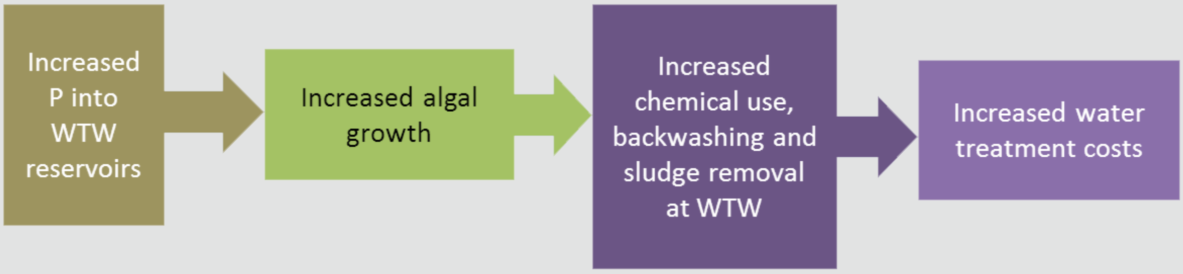

Figure 4.12 Schematic summary of the linkages from water quality parameters to estuary ecosystem services for a case of deteriorating water quality.

The relationships between water quality and fish abundance have been well studied in KwaZulu-Natal (Cyrus & Blaber 1987, 1988). Expert understanding of these and other relationships is used in the quantification of estuarine responses to changes in in the quantity and quality of freshwater inflows to estuaries. A substantial amount of work has also been carried out by groups of estuarine specialist scientists to describe the present status of estuaries throughout South Africa, following standardised methods of describing estuarine health developed for the setting of environmental flow requirements as well as for estuary management more generally (Turpie et al. 1999, 2012). These require the description and scoring of all the abiotic and biotic components of estuaries, including water quality variables and fish communities. These scores have been collated and summarised for the most recent National Biodiversity Asssement of estuaries (van Niekerk & Turpie 2012).

Analysis of the health scores for the 16 estuaries in the study area revealed a strong linear relationship between a sub-element of the overall water quality score (based on nutrients, TSS, oxygen and heavy metals, but not salinity), hereafter referred to as the Water Quality Score (excluding salinity), and the Fish Score (Figure 4.13).

The effect of nutrient and TSS loads on the Water Quality Score was then determined based on the relationship between modelled annual loads for the EMA estuaries and the Water Quality Score. The annual loads were first standardised to account for differences in catchment size, characteristics and rainfall by expressing them in terms of natural Mean Annual Runoff. After exclusion of two outliers, there was a significant negative logarithmic relationship between the standardised N, P and TSS loads and the Water Quality Score (Figure 4.14). These relationships were used to estimate changes in the Water Quality Score as a result of loss of the natural vegetation in the catchment, and to estimate the consequent impacts on fish populations and values.

The modelled loads under the status quo and the two alternative scenarios (removing the ecosystem service) were then used to generate modelled water quality scores. The percentage difference in these scores was used to adjust the actual water quality scores. The latter were then used to estimate diffrences in the fish scores. Again, these differences were used to adjust the actual fish scores. Finally, the proportional change in fish scores was used to estimate changes in the fishery and nursery values of each estuary, as a measure of the damage costs avoided.

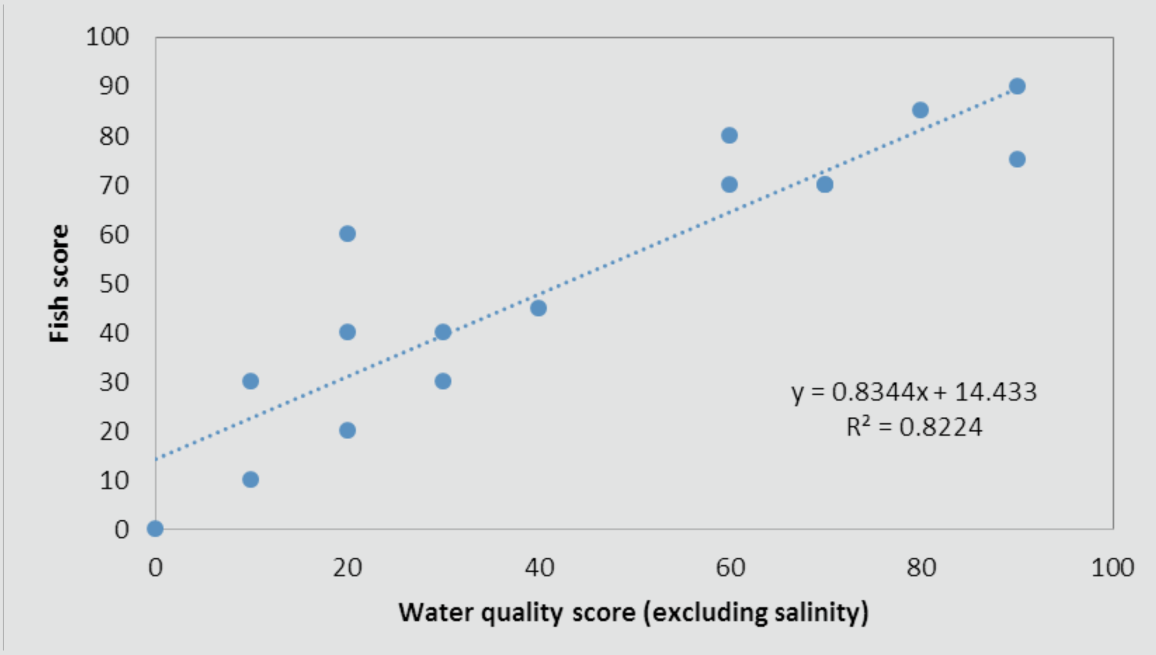

Figure 4.13 Relationship between water quality and fish scores for the 16 estuaries of the eThekwini municipality.

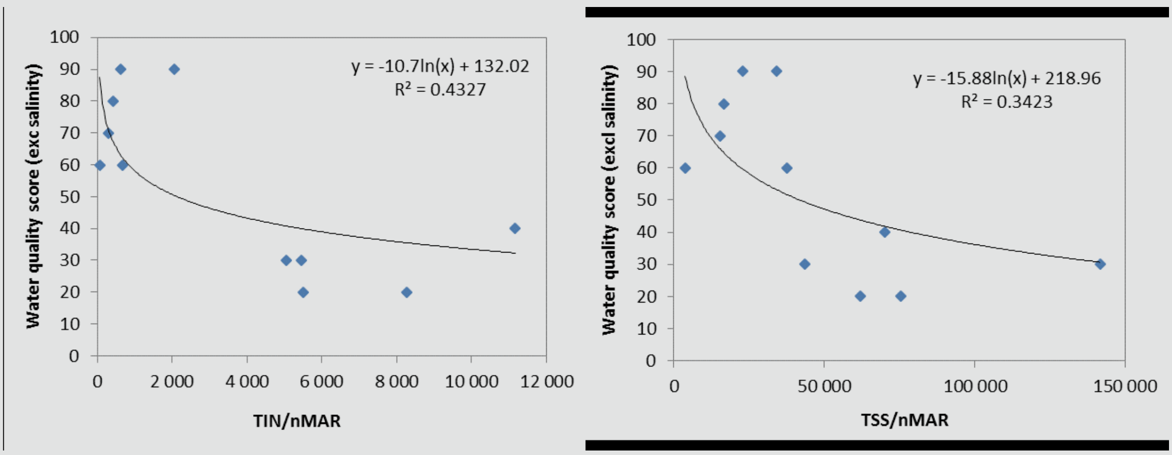

Figure 4.14 Relationship between modelled annual loads of TIN and TSS and the Water Quality Scores for estuaries of the eThekwini municipality.

Table 4.8 Annual water treatment cost savings associated with the three water supply dams in the EMA

Dam	Without vegetation (min)		With settlement (max)	
	Increase in treatment cost (R per ML)	Total annual water treatment cost savings (R millions)	Increase in treatment cost (R per ML)	Total annual water treatment cost savings (R millions)
Inanda	7.45	0.734	44.96	4.43
Hazelmere	8.12	0.154	193.80	3.68
Nungwane	8.77	0.067	74.61	0.57
TOTAL		**0.955**		**8.68**

Phosphorous loads entering the water supply dams as a result of the loss of natural vegetation were estimated to increase by 193%-319%x for Inanda Dam, 193%-968% for Hazelmere and 200%-509% for Nungwane Dam, with the lower values being an estimate of actual current levels of removal and the higher values incorporating the potential additional inputs that would occur under changed land use, which is effectively the cost avoided by conserving the current land use. Using these estimates and the water treatment cost model for Wiggins WTW and Durban Heights WTW it was estimated that the cost saving to water treatment works is between R1 million and R8.7 million per annum (Table 4.8). The Changes were greatest for Hazelmere dam, which has a large area of natural vegetation in its catchment.

In addition, it was estimated that the maintaining the existing areas of natural vegetation avoids potential losses in estuary fishery and nursery values of between 2 and 48% (Figure 4.15). The total avoided loss as a result of the water quality amelioration function of natural vegetation in the estuary catchments was estimated to be in the order of R2.19 to R3.71 million per annum. Overall, water quality amelioration services were estimated to be worth between R3.15 and R12.39 million per annum, the average of which is R7.77 million. This translates to a NPV of R89.3 million.

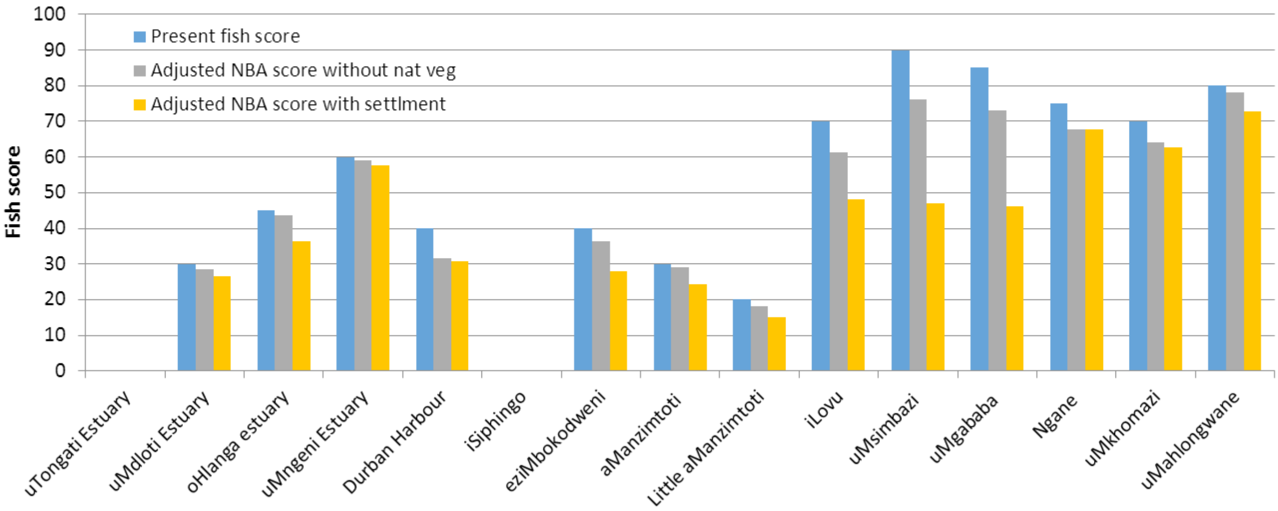

Figure 4.15 Estimated avoided losses of estuary ecosystem services due to the water quality amelioration function of natural vegetation in the estuary catchments.

Values derived from the above analyses were mapped to the green open space areas within each catchment using an estimate of the relative contribution of different land parcels to phosphorous and nitrogen retention modelled using InVEST modelling software (Glenday 2012). This provided the relative phosphorous and nitrogen retention score given to each grid cell within the EMA based on rainfall, soil and landcover. The value per pixel was then determined for all green open space areas (based on the latest GIS data of D'MOSS), total phosphorous and nitrogen retention value for each catchment, the retention score given to the pixel and the sum of all pixel retention scores. The value per pixel was then divided by the area of the pixel to arrive at a phosphorous and nitrogen retention value per hectare estimate for all green open space areas in each catchment. The values for phosphorous and nitrogen retention were then summed to get a total value per hectare for nutrient retention (Figure 4.16).

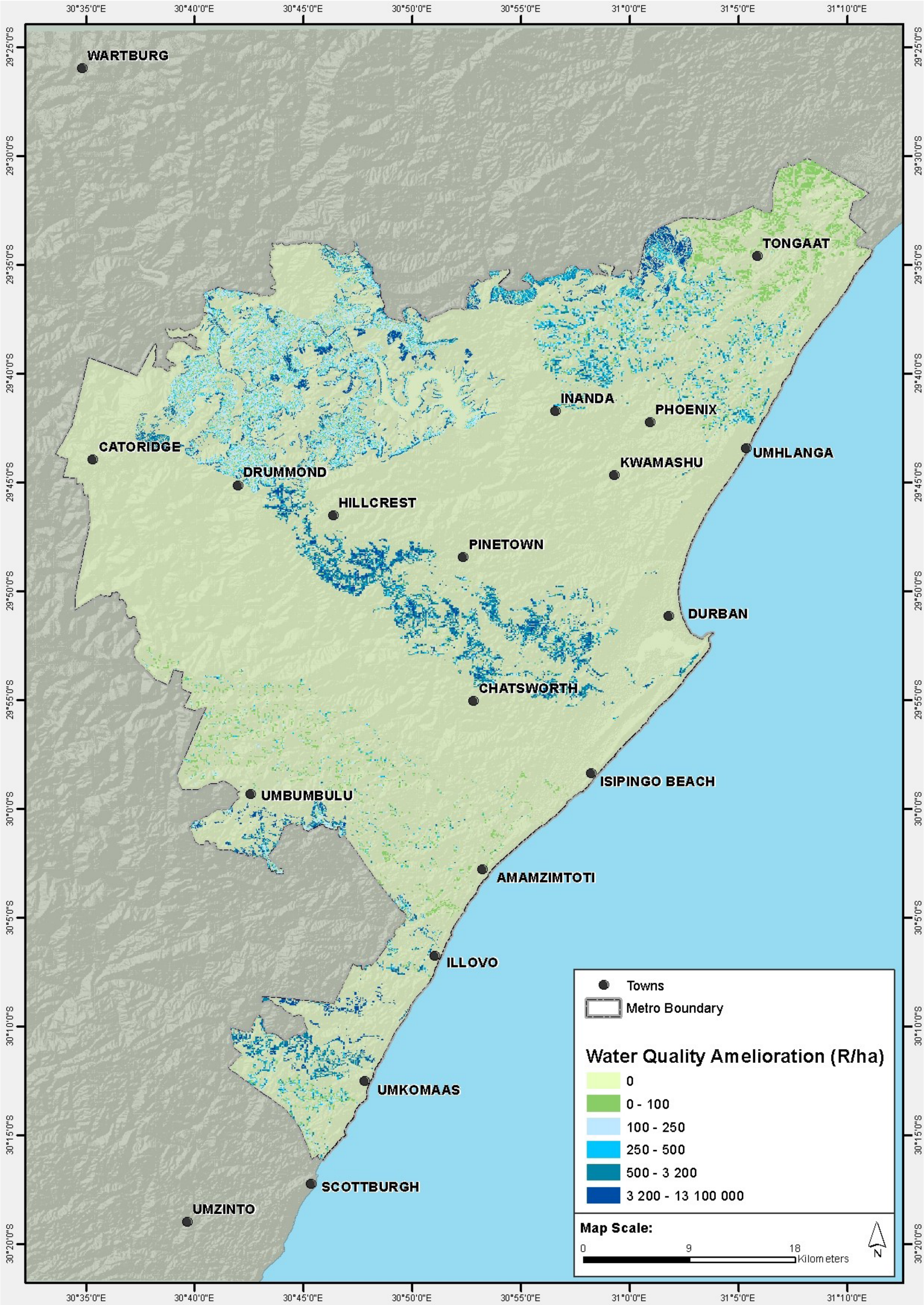

Figure 4.16 Water quality amelioration value associated with natural systems (D'MOSS) (NPV, R/ha) in the EMA

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V. AMENITY VALUE

5.1 Introduction

Durban has been rated as the city with the highest quality of living in South Africa (based on the Mercer rankings of 230 cities in the world). Many factors contribute to quality of living, including environmental factors such as cleanliness and air quality, and the amenity value provided by natural and semi-natural systems.

The amenity value of urban green open space areas is derived from their individual combinations of natural attributes such as size, beauty and rarity, and man-made enhancements such as pathways, lawns and security. These attributes determine the extent to which each area is suitable or attractive for recreational use, religious use or spiritual fulfilment. Their value, or actual contribution to human welfare also ultimately depends on factors that influence demand for these services, such as the number and income levels of people living in the vicinity, as well as by people living elsewhere. Users of urban parks have described them as rejuvenating, relaxing, break from daily routine and spiritual reconnection with the natural world (Chiesura 2004). Other studies have shown that public parks reduce stress (Ulrich & Addoms 1981) and provide a sense of peacefulness (Kaplan 1983). Therefore, public parks benefit emotional and psychological health and are a key component to sustainable development (Chiesura 2004). In fact, the lack of green open spaces is the primary reason why people left the city of Leuven, Belgium, and sought properties on the urban fringe (Van Herzele & Wiedemann 2003).

Because of the intangible nature of these values, the welfare gains generated by the supply of cultural services are difficult to estimate and map (Milcu et al. 2013). In theory, the value of the cultural services provided by existing green open space areas is what people would demand in compensation for giving up the benefits they receive from those spaces. This can be estimated through the use of stated preference methods, involving surveys of users that elicit their willingness to pay to retain or willingness to accept compensation to forgo a certain state of the world. However, the inherent methodological biases of these methods can be extremely challenging, and require very comprehensive studies. No such studies have been carried out within the Durban area.

Nevertheless, the welfare gains associated with the amenity of green open space areas are reflected to a large extent in two markets that are observable – property and tourism. Urban residents often pay a premium to live close to the areas they enjoy, or to have a good view. Similarly, visitors pay to travel to and stay in an area where they will have access to or views of different types of amenities. Thus one can determine amenity value by using revealed preference methods, in which actual data from related markets are analysed in order to estimate the contribution made by a feature of interest, in this case green open space. It is fair to assume that the two values derived are from two separate user groups and can be added together. These two types of value are analysed separately below.

5.2 Amenity value to property owners

The value that residents place on open space is reflected, to an extent, in private property and real estate markets. When buying a home, certain preferences for different characteristics are revealed through the amount that each homebuyer is willing to pay for the property, with homes that have a higher number of desirable characteristics usually selling for a higher price. Property attributes include the physical characteristics of the home such as size of the living area, number of bathrooms and condition, neighbourhood characteristics such as access to amenities, and environmental characteristics such as scenic views and the amount of green open space surrounding a property. Therefore if residents do value open space then it would be expected that these values should be revealed in property prices.

A hedonic property value approach was used to estimate the value associated with different types of green open space within the EMA. A total of 16 149 property transactions, provided by the eThekwini Municipality Real Estate Department, were analysed over a two year period from January 2012 to October 2014. The dataset included several characteristics of each property. Each property in the dataset had a unique PIN which allowed us to determine its location by matching each property sale with a property boundary (erf) in the eThekwini GIS cadastral layer. Using GIS data, the areas of different types of natural open space such as forests, woodlands, rivers and grassland as well as recreational green open space such as public parks and golf courses within different distances of each property were determined. The condition (good, intermediate, degraded) of the natural open space was also considered as it was assumed that degraded patches of natural vegetation may influence property price differently to patches in a good condition. Distances to the CBD, private schools and the coast were also calculated. In addition, the characteristics of each neighbourhood (or suburb), such as population density and average household income, were collated from Census 2011 data. Average tree cover was also calculated for the streets in each suburb. The property prices were then analysed in terms of the property characteristics, neighbourhood characteristics and access to green open space (Table 5.1) using ordinary least squares (OLS) regression. The analysis is described in detail in Appendix 6).

Table 5.1 Property, neighbourhood and green open space characteristics included in the hedonic analysis

Property characteristics	Neighbourhood characteristics	Green open space characteristics
Total Living area (m2)	Distance to CBD (km)	Amount of natural vegetation (ha)
View from property	Population Density (ppl/km2)	Length of river/ stream (m)
Security	Modal household income (R)	Amount of sugarcane farmland (ha)
Condition	Distance to nearest school (m)	Sub-place greenness: tree cover (%)
Presence of a garage	Amount of commercial land (ha)	Amount of golf course area (ha)
Presence of a swimming pool	Amount of industrial land (ha)	Amount of park area (ha)
	Amount of major road network (ha)	Distance to nearest coastline (km)
	Distance to nearest coastline (km)	

In order to spatially assign a value to the green open space in the EMA it was necessary to calculate the premium associated with natural open space and park land and aggregate the model results. This was achieved by assigning a census level sub-place and main-place to each property and the effect of open space on property values was calculated using the estimated model coefficients, which provided a percentage change in property value given a unit change in the value of the open space variable under consideration. The aggregate effect was then estimated by by applying the modelled regression results to the entire stock of residential houses within each sub-place of the EMA. The value (R/ha) associated with each area of open space or park land was calculated based on these total premiums and the total amount of green open space present within each main-place census unit.

The results revealed that the type of open space and the condition of open space have very important influences on the amenity value associated with these areas, with natural open space areas in a good condition attracting significant and positive price premiums and those in a degraded condition attracting negative price premiums. Natural open space areas that are not formally protected are often targeted by people moving into the city with no place to live, often being transformed into informal settlement sites. As a result, degradation and a general decrease in attractiveness of these areas occurs. Degraded open space patches are also often associated with crime, making them even less desirable in terms of their proximity to properties and their accessibility. Unexpectedly, river systems, regardless of their condition, had a negative impact on housing prices. While the percentage decrease on property value was relatively small, it is still surprising that even when in a good condition the proximity to rivers is considered negative. This could be that people prefer to have views over river gorges, such as in the areas of Hillcrest and Kloof, but consider rivers in close proximity to property as a negative influence as similarly to natural open space areas, they are known to attract informal settlements, are prone to flooding and can be considered breeding grounds for unfavourable insects such as mosquitos. Man-made green open space, such as golf courses and park areas both had a significant positive effect on house prices.

The total premium associated with natural open space in a good condition was 2% of overall property value, which amounted to R4.4 billion with an average value of R108 900 per ha (Figure 5.1). This is only part of the asset value of these areas, which also provide other ecosystem services. The highest values were situated within the main urban core of the EMA (R1.4 million per ha in Durban MP) and along the coastline where high quality natural coastal forests are still intact (e.g. Umhlanga – R3.4 million per ha). The values were also higher in and around the suburbs of Hillcrest and Kloof (about R1 million per ha), both being affluent areas, much like the coastal suburbs of Umhlanga and Durban MP, whereas they were lower in inland suburbs such as Cato Ridge (R37 500 per ha) and Pinetown (R423 000 per ha).

The total premium associated with public parks was approximately 6.4% of overall property value, amounting to a total of R13.8 billion with an average value of R14.7 million per ha (Figure 5.1). and an average value of R14.7 million per hectare. This is more than three times the total value associated with natural open space in a good condition. Park value is highest in and around the urban core of Durban city but is also important in other densely populated areas such as Chatsworth, Phoenix and Pinetown. With an average population density in Chatsworth of 5500 people per km2 and in Phoenix 6400 people per km2, both higher than the EMA average, it is clear why residents in these areas may value public open space more than residents living in less dense areas with larger-sized properties. Park areas offer more recreational opportunities when compared to natural open space areas and it is also thought that safety and security play an important role in where residents choose to enjoy green open space in the city, with public park areas often more safe than natural dense vegetated areas.

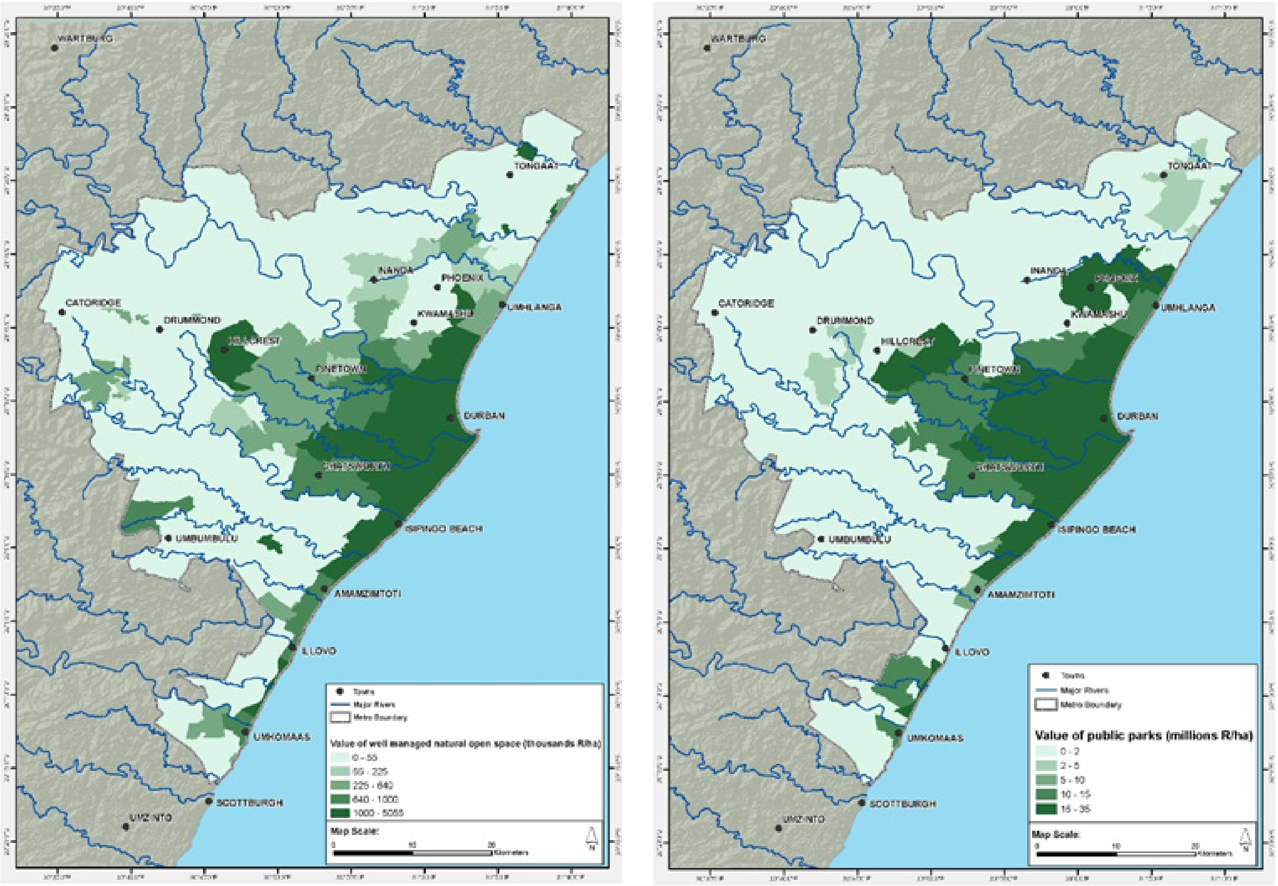

Figure 5.1 Average value (R/ha) of (a) natural open space in a good condition and (b) parks within each main-place within the EMA. Note: the actual location and extent of open space areas within each EMA is not shown due to scale.

The combined value of green open space areas in the EMA, both natural and man-made, was estimated to be R18.2 billion. Based on the these values, the presence of well managed green open space in the eThekwini Municipality contributes an estimated R356 million per annum in property tax revenues to the city. This would account for more than 5% of total property rates income to the municipality. These results provide a useful understanding for future development in Durban and highlight the importance of maintaining healthy natural open space areas.

5.3 Tourism value

The city of Durban is a leading tourism destination in South Africa. The year-round warm weather conditions encourage leisure tourists to enjoy the many outdoor tourist attractions such as the extensive beaches and beachfront promenade, the uShaka Marine World and the SkyCar and bungee swing at the Moses Mabida World Cup Stadium, as well as sporting events. The beach and marine/coastal environment is the core leisure tourism experience offered in Durban (eThekwini Municipality 2014b). According to recent surveys, going to the beach was the main activity for 50% of international tourists and 83% of domestic tourists to KwaZulu-Natal (SAT 2014).

In 2012, some 15.5 million people visited the city, resulting in a total expenditure of about R5.7 billion (eThekwini Municipality 2014b). Some 15% of these visitors are foreign, and 57% of all visitors are holiday visitors (eThekwini Municipality 2014b). Based on data in WTTC on tourism growth and multipliers (WTTC 2015), total expenditure by domestic and foreign tourists was estimated to be R6.718 billion in 2014. This expenditure would have resulted in a total GDP contribution of R9.75 billion. Of this, leisure tourists were estimated to contribute som R5.56 billion (Table 5.2).

Table 5.2 Estimated expenditure and valued added by tourists visiting Durban in 2014 (R billion).

	Expenditure (R billion)	Direct Value Added (R billion)	Total Value Added (R billion)
All tourists	6.718	3.138	9.753
Leisure tourists	3.829	1.788	5.559

There are no survey data on the extent to which visitors are attracted by or make use of the natural assets within Durban, however. While it is acknowledged that many of the scenic and nature tourism attractions are not well known or well developed for tourism (eThekwini Municipality 2014b), these areas do already make some contribution to the value of tourism in the EMA. For example, the uMngeni River plays host to the annual Dusi Canoe Marathon, and the Inanda Dam is used for fishing competitions, endurance events and a number of other watersports.

Nature-based activities such as walking and bird watching are also important in certain areas, such as on estuaries and wetlands and in nature reserves within the EMA, and undoubtedly add value to the tourism experience. There are 21 Municipal Parks and Nature Reserves within the EMA and six Ezemvelo KwaZulu-Natal Nature Reserves, making up about 14% of the D'MOSS area (eThekwini Municipality 2012). These range in size from small bird sanctuaries to large nature reserves, and they vary in terms of their visitor facilities. Two of the most popular are the Durban Botanical Gardens and the 584 ha Krantzkloof Nature Reserve situated on the coastal escarpment between Pinetown and Hillcrest. Krantzkloof features scenic river gorges, excellent views, indigenous coastal forest and grassland and an abundance of bird life, and has well-utilised paths for walking and trail running. There are also nature reserves associated with the water supply dams (Shongweni, Hazelmere and Inanda) within the EMA and these are managed by Msinsi Resorts and Game Reserves.

Determining the tourism value of particular areas such as parks or nature reserves usually involves on-site surveys of tourists and the collection of user statistics to determine expenditure on visiting these areas, and using revealed preference methods such as travel cost analysis in order to determine their consumers' surplus, or the net welfare gains resulting from the use of these areas (Willis & Benson 1989, Shrestha et al. 2007, Wood et al. 2013). These kinds of methods are impractical for estimation of the value of multiple sites across an extensive area. Most efforts to quantify and map cultural services such as recreational value, have used the number of visitors to an area as a proxy (Hill & Courtney 2006). Other proxies include number of tourist attractions, tourist expenditure, sightings of rare species, accessibility to natural areas and days spent fishing (Raudsepp-Hearne et al. 2010; Chan et al. 2011; O'Farrell et al. 2011). More comprehensive studies typically rely on household or off-site user surveys (e.g. from a database of people with fishing licences) or on-site choice decisions to estimate values using a random utility modelling framework. However, these methods have only really been applied to the use of local or regional amenities by residents of a city or region. Determining the contribution of multiple natural amenties to tourism value might involve broader-based tourism surveys with dedicated questions on the use of these amenities. For example, Tyrväinen & Väänänen (1998) used the Contingent Valuation Method (CVM) to determine the benefits of urban forests and Fleischer & Tsur (2000) used a combination of these two methods to establish the recreational value of the agricultural landscape. Where many such studies have taken place, it is possible to use the findings to map recreational value using extrapolation techniques. For example, Sen et al. (2011) did an economic assessment of the recreational value of ecosystems in Great Britain using a recreation valuation model which they developed, using recreational survey data as well as land use and population data. However, these methods generally require a large amount of data which is expensive and time consuming to collect especially at large geographic scales. In Durban, none of the above such surveys have been carried out, and user statistics are only collected at a handful of paying nature reserves.

The recent emergence of various social media tools provides an alternative to assess how people respond to nature and open space areas (Wood et al. 2013). One such way of doing this is to analyse the pattern of georeferenced photographs taken by the public and uploaded onto the Internet. For example, Panoramio hosts photographs from all over the globe, focusing on images of landscapes, natural features and animals in their natural environment. Images that focus on people, interiors, paintings, logos and events are excluded from the website (Panoramio 2015). Geo-tagged imagery can provide information about the places depicted in the photographs, as well as the interests, behaviours and mobility of the people who took them (Andrienko et al. 2009).

The number of people using the internet has increased to nearly 100% on a global scale (International Telecommunication Union 2012). Several researchers have begun to use social media data for mapping of recreational ecosystem services, and to determine the appeal of a particular natural asset to both tourists and locals (Alfaro 2015, Kachkaev & Wood 2013, Howarth 2012). An advantage of this approach is that data are often free and quicker to access than by traditional means (e.g. surveys and hedonic pricing). Furthermore, it holds "big data" (Goes 2014), because an enormous amount of information is submitted by millions of users worldwide. This "big data" is available through virtual sources which can be utilised by academics, consultants and organisations that are looking to evaluate people's preference for certain natural commodities (Alfaro, 2015). For instance, six billion images have been uploaded onto Flickr by Yahoo, to its public database alone. Social media websites such as Flickr and Panoramio (by Google) can therefore provide a wealth of information through their numerous geo-tagged photographs for example location, distribution and types of interests, in addition to users' demographics (Wood et al. 2013).

The use of geo-tagged photo data method is based on the premise that the numbers of photographs uploaded to these sites are correlated with the recreational value of different areas (Casalegno et al. 2013). Several studies have used this method. Turpie (2011) used photographs from Panoramio.com to estimate landscape contribution to tourism value in an undeveloped area of Nambia. Li et al. (2011) used parameters recorded by tourists' digital cameras and stored in Panoramio to determine tourists' temporal variations, length of stay, daily average number of tourists, individual movement traces and a flow map. A non-parametric density estimation called a kernel density estimation was then used to generate tourism hotspots (Li et al. 2011). Casalegno et al. (2013) used the number of individuals (expressed per 1 km2) who uploaded photographs onto Google Earth (via Panoramio) as a measure of recreation rather than the total number of photographs. They made the argument that this method was more appropriate when analysing hotspots as the total number of photographs in an area reflects the level of activity of individual photographers rather than the overall value placed on a site by visitors. Turpie et al. (2014) used a kriging method to analyse patterns of Panoramio photo uploads to map tourism value in Zambia. Alfaro (2015) used photographs taken from Panoramio and Flickr to estimate the distribution of recreational services in Nebraska. By determining the location of clusters of photographs and comparing these clusters to population density, the researcher was able to identify new areas of high recreational value.

In this study, photograph data were extracted from Panoramio (wwww.panoramio.com) for the study area using a grid of 0.025 degrees (roughly 2.75 x 2.4 km) which was created in ArcGIS® 10.1 (Esri® 2012). The API programming command was set to count all photographs, including duplicates of the same subject by different photographers. The size of the grid cell was selected in order to achieve a sufficiently fine resolution without being too small, given that the subject of photographs can be expected to be at a distance of up to 100 m or more from the camera, and given the overall numbers of photographic uploads.

A total of 10 016 photo uploads were obtained from Panoramia within the EMA boundary. The highest concentration of photographic uploads were in areas that were easily accessible, such as along the Durban and Umhlanga beachfront where there are a number of hotels, guesthouses, walkways, restaurants and other tourist activities and facilities (Figure 5.2). A large proportion of photographs were taken along the National Route 2 (N2) highway that runs parallel to the coastline and the National Route 3 (N3) highway that runs west towards Pietermaritzburg from the Durban city centre. High concentrations of photographs are also found in the high-income suburbs along the N3 route, such as Kloof and Hillcrest. Protected areas also had large numbers of photographs associated with them. Other popular attractions noted during the photograph analysis were golf courses and sports grounds. A significant proportion of the photographs taken in and around the Durban city centre are of cultural and commercial content, such as photos of museums, historic statues and shopping malls. The high density of photographs along the length of the EMA coastline highlights the importance of the marine environment in attracting tourists to the area. Few photographs were taken in rural areas surrounding the main urban core of the EMA, probabloy because these areas are less accessible to visitors and much of this land is private or tribal.

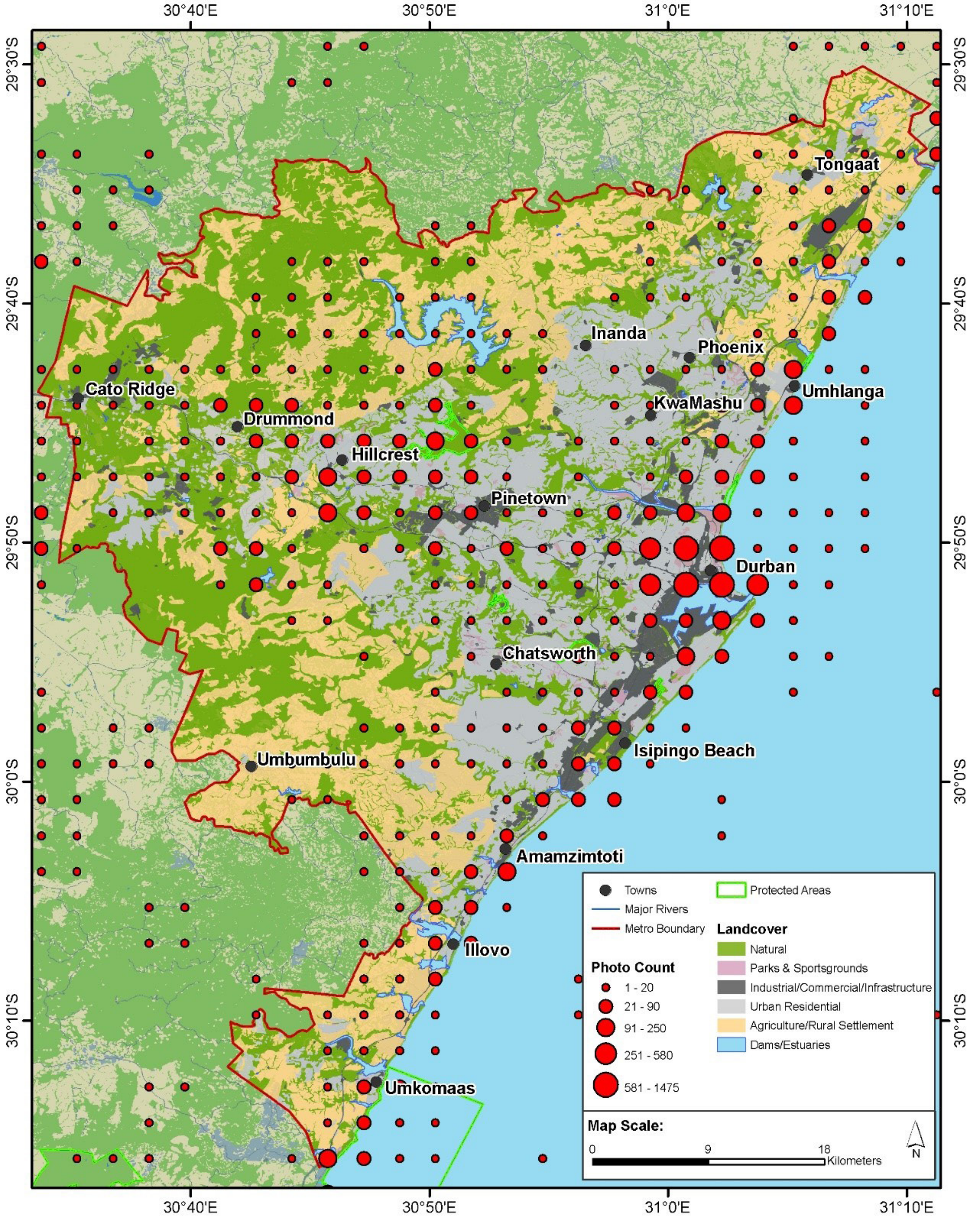

Figure 5.2 Pattern of geo-tagged photo uploads in relation to major land cover types within the eThekwini Municipal Area.

Statistical analysis of these patterns in relation to the features of the different grid cells showed trhat the numbers of photographs were significantly influenced by the presence of certain land cover types, and that the interaction of man-made and natural features was important in determining the attractions of the latter (see Box 5.1 for details).

Box 5.1 Analysis of photo densisty

A generalized linear model was then used to analyse the numbers of photographs per grid cell in relation to the extent of different land use/land cover types within each grid cell. This was to determine the factors influencing the relative values of the cells.

A semi-log model was used for the analysis where the dependent variable was the natural log of the photo count within each grid cell. The independent variables included in the model were based on a number of different land uses and land cover types as adapted from the combined D'MOSS and LULC map. These included the amount of commercial/retail land, industrial land, roads, urban settlement, informal settlement, rural settlement, agricultural land, parks, golf courses, natural land not within protected areas, land within protected areas, dams, estuarine and marine areas. Interaction terms were included e.g. to account for accessibility in reaching certain land cover types.

Data were analysed using ordinary least squares (OLS) regression in R Project for Statistical Computing (ver. 3.2.0). Collinearity amongst variables was tested and those that displayed high levels were removed from the model as suggested by the software analysis through stepwise regression techniques. The model estimation results are shown in Table 5.3.

Table 5.3 Model estimation results

	co-efficient	std. error	t. value	Pr(>|t|)	
(Intercept)	1.09	0.11	10.25	< 2e-16	***
Commercial	0.02	0.0042	4.52	8.02E-06	***
Industrial	0.0027	0.0012	2.29	0.0228	*
Urban Settlement	0.0010	0.00	2.64	0.0087	**
Rural Settlement	-0.0013	0.00	-3.27	0.0012	**
Golf Course	0.0143	0.01	1.86	0.0631	.
Horse Racetrack	0.0340	0.01	2.29	0.0223	*
Protected Areas	0.0111	0.00	3.89	0.0001	***
Dam	0.0035	0.00	1.80	0.0728	.
Estuary	0.0138	0.00	5.45	8.64E-08	***
Natural Land*Road	0.0003	0.00	5.69	2.49E-08	***
Marine*Built Env.	0.0007	0.00	6.93	1.74E-11	***
Sample size				414	
R-squared				0.5	
Adjusted R-squared				0.48	

Notes: (1) ***p<0.001, **p<0.01, *p<0.05, .p<0.10.

The results indicated that accessibility is an important factor in the value of natural open space. Natural open space outside of protected areas only had a significant effect in interaction with roads. Similarly, coastal environment had a significant effect in interaction with the built environment (commercial and urban settlement areas only), reflecting the importance of beach front accommodation and amenities. Photographs often included beachfront activities or views of the beach from hotels and restaurants along the coastal strip. Natural open space within protected areas was highly significant, with these areas having a high number of photographic uploads. Dams and estuaries were both positive and highly significant, with high concentrations of photographic uploads of these features. Rural settlements had a negative influence on photograph counts due to the low number of photgraphic uploads in these areas as a result of visitor inaccessibility. Urban, commercial and industrial land cover had a positive and significant influence on photographic counts due to the high numbers of architectural and cultural photographs taken in the urban areas across the EMA. Variables that did not influence model results included informal settlements, parks, sports grounds and agricultural land.

The statistical distribution of the number of photographs was negatively binomial. In order to test whether the relationship between tourism value and photo densities should be linear or non-linear, we conducted a broad-scale test at the national scale, using photo uploads at the 0.25 degree scale and national parks visitor data for 2014. On the basis of this, it was assumed that leisure tourism value was directly proportional to photo numbers. Therefore the proportion of leisure tourism value derived from any grid cell was assumed to be equal to the total value multiplied by the percentage of photo uploads in that grid cell.

The relative importance of places of interest to leisure-based tourists (whether for cultural, architectural, nature-based or other reasons) was assumed to be reflected by the spatial distribution of georeferenced photograph uploads on Panoramio.com. In order to estimate the contribution of different attractions to tourism value, the contents of the photographs were analysed. The content (or setting) of each photograph in each grid cell was examined[1] and put into one of five categories; (1) built environment, (2) natural open space, (3) man-made open space, (4) rural or agricultural, and (5) marine or coastal. The built environment category included urban, dense rural and informal settlements, as well as commercial/retail land, rail and industrial land. Following this, the percentage contribution of different settings to tourism value was determined for each grid cell. The corresponding value was then assigned to the actual land cover within each grid cell in the EMA based on the combined LULC/D'MOSS map.

In this way, the total value added by leisure tourism (R5.6 billion; Table 5.2) was assigned to five different land use classes within each grid cell. The total nature-based tourism value was mapped using GIS and is shown in (Figure 5.3). A number of the natural areas with the highest values were located within nature reserves, such as Kranzkloof, Shongweni, Beachwood and Umhlanga Lagoon. Estuaries, such as Durban Bay and uMngeni also had high values. The total tourism value assigned to natural habitats (natural vegetation, freshwater systems, estuaries and the coastal environment) was almost R2 billion and accounted for 40% of all photographic uploads (Table 5.4) with the coastal environment contributing just over half of this value. The tourism value associated with the coast was very high, with the most popular coastal areas having values of up to R66 million per kilometer stretch of coastline (Figure 5.3). Man-made open space such as parks and golf courses had a total leisure tourism value of R382 million at an average value of R234 000 per hectare. Therefore the combined tourism value of natural and man-made open space is approximately R2.4 billion.

Table 5.4 The overall leisure tourism value (R million) and % photographs for the five land use categories.

Category	Total Leisure Tourism Value (R million)	Overall % Photographs
Built Environment	2 929	42.3
Rural/ Agricultural	232	15.2
Natural Open Space	928	31.8
Man-made Open Space	384	2.6
Marine/ Coastal	1 085	8.2
TOTAL	**5 559**	**100**

[1] This analysis was achieved by downloading the details of each photograph from each grid cell using code developed by Panoramio. The output for each grid cell produced information about the number of photographs, the number of users taking the photographs, the title of each photograph and a url link to each photograph in Panoramia.

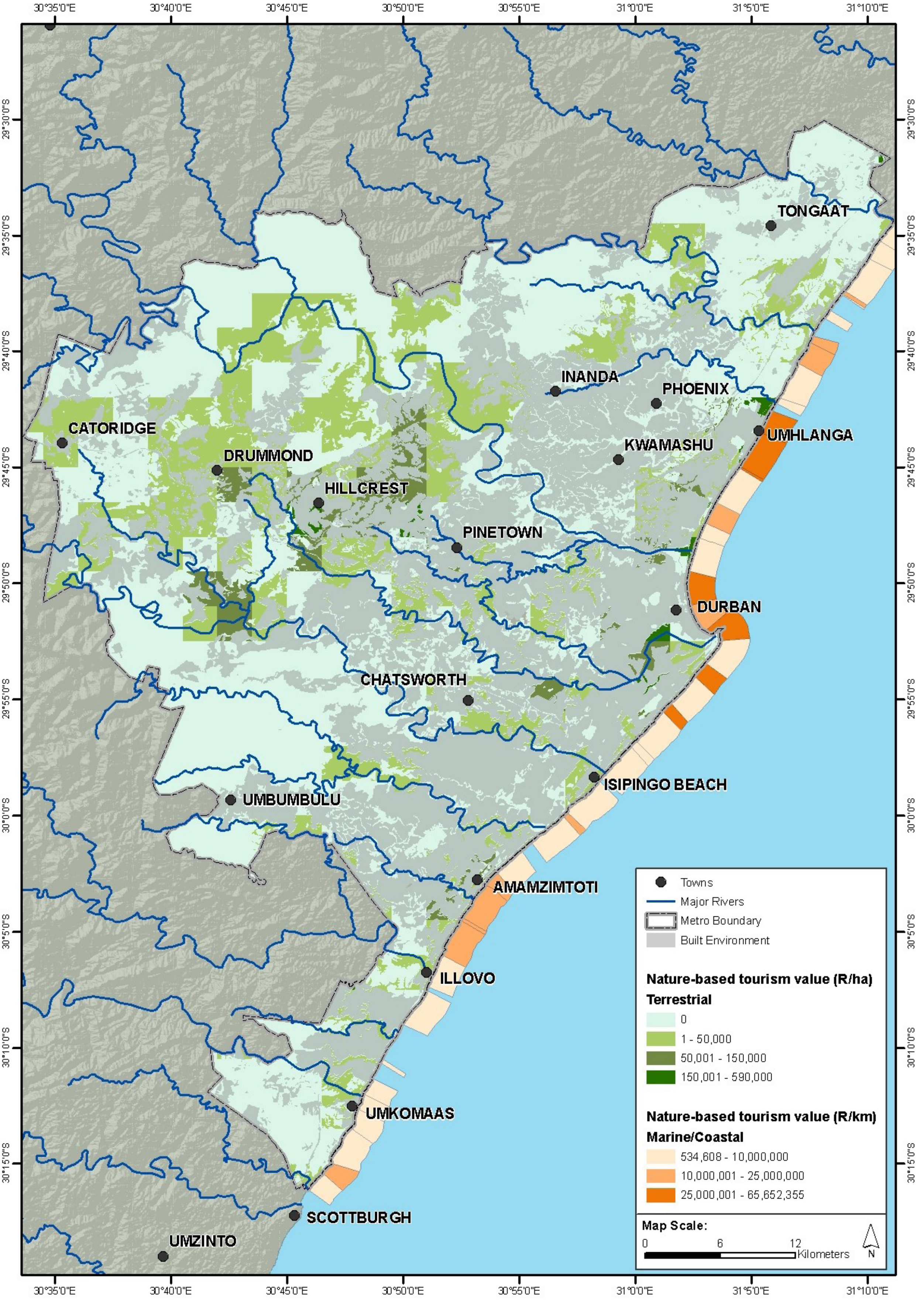

Figure 5.3 Nature-based tourism value in the EMA shown for terrestrial natural open space as R/ha and for the coast as R/km.

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VI. SUMMARY AND CONCLUSIONS

Natural and semi-natural systems within the eThekwini Municipal Area give rise to flows of ecosystem services worth in the order of R4.2 billion per year. In 2002 the value of Durban's Metropolitan Open Space System (D'MOSS) was estimated to be R3.1 billion per annum excluding tourism value (eThekwini Municipality 2002). This earlier study raised public sector awareness of the value of these areas, and resulted in improved allocation of resources for their management. These value estimates were extrapolated from international studies (mainly Costanza et al. 1997) on the basis of total areas of different habitat types within the city. Wetlands and forests were valued at about R160 000 and R21 000 per hectare per year, respectively. The Costanza-derived values were higher than our estimates, as expected, due to the inherent bias in the data from which they were derived. The updated study has shown that cultural services are the dominant values of urban green open spaces and make a substantial difference to estimates of overall value.

Based on a 20-year time horizon and a discount rate of 6%, the total asset value of the natural and semi-natural capital in the eThekwini Municipal Area that encompasses the city of Durban and surrounding peri-urban and rural lands, was estimated to be at least R48 billion (Table 6.1). The true value is probably much higher. For instance, applying a social discount rate of 3% would yield a value about 30% higher, or around R62 billion. The results from this study have shown that ecological infrastructure in cities is not only environmentally and socially desirable, but is also beneficial from an economic point of view with numerous benefits accruing from natural open space areas.

The provisioning value natural systems was estimated to be R1.1-1.5 billion (NPV), with fuelwood and river water contributing the most to this value. Considering water is collected from rivers and streams by only 0.5% of the population in the EMA, this resource is thought to be the most valuable in terms of the service it provides per user household. The remaining values represent approximately R225-292 million of the total provisioning value of natural resources in the study area (Table 6.1). Regulating services have a net present value of about R1.0-1.2 billion with carbon storage and flow regulation accounting for 39% and 34% of this value, respectively. This value is believed to be a conservative estimate. The many benefits derived from these supporting services are indirect and particularly difficult to value, and most of the regulating services also play the role of supporting services that influence the outputs of other ecosystem services. The amenity value associated with natural and semi-natural open space areas in the EMA was estimated to be R45.7-59.4 billion, 96% of the overall value of ecosystem services (Table 6.1).

Generally, ecosystem services in urban areas are characterised by high demand/use due to the large number of immediate local beneficiaries, compared to ecosystem services generated in rural sparsely populated areas (Elmqvist et al. 2015). The spatial representation of the relative value of ecosystem services, or the mapping of geographic variation in these values, provides the opportunity to compare areas and types of values. The relative value, expressed as net present value per hectare, can be compared across groups of services and can be used to identify areas of importance based on the relative values associated with different areas in the EMA. The geographic variation between groups of services is shown in Figure 6.1. A summary of the total net present value associated with estuaries (subsistence fishery value and nursery value) is included in Table 6.2. These values were not included in Figure 6.1 due to scale issues associated with mapping smaller estuaries. The provisioning and regulating services provided by estuaries have a net present value of R203-263 million with Durban Bay, uMngeni Estuary and uMkhomazi Estuary accounting for 36.2%, 12.7% and 10.9%, respectively (Table 6.2). However, the seven estuaries along the south coast from iLovu to iMahlongwa have the highest relative values, largely a result of being in a better condition compared to the estuaries further north.

Within the city, and overall, amenity value is by far the most important economic value of natural and semi-natural open space. This large value is derived from a small proportion of the D'MOSS (Figure 6.1). The patterns observed for property value (representing value to residents), and tourism value were similar, with certain areas in the EMA contributing significantly to both. These areas include the natural open space areas in Kloof and Hillcrest, the nature reserves along the coast such as Beachwood, and the central areas of Durban city centre, Durban Bay and the beachfront promenade.

Table 6.1 Total value of ecosystem services in the EMA. Values in R millions (2015).

Ecosystem services	Annual Value	NPV (20 y, 6%) (R millions)	NPV (20 y, 3%) (R millions)
Provisioning services			
River water for domestic use	31.8	364.7	474.1
Fuelwood	46.5	533.4	693.4
Timber poles	6.6	75.7	98.4
Food and medicinal plants	4.7	53.9	70.1
Grass and reeds	1.4	16.1	20.9
Bush meat	0.6	6.9	9.0
Fishery resources	6.3	72.3	94.0
Sub-total	**97.9**	**1 122.9**	**1 459.9**
Regulating services			
Carbon storage	34.3	393.4	511.4
Agricultural support	1	11.5	15.0
Fisheries support (nursery function)	11.4	130.8	170.0
Flow regulation	29.5	338.8	338.8
Sediment retention	3.1	35.2	45.8
Water quality amelioration	7.8	89.1	115.8
Sub-total	**87.1**	**998.8**	**1 196.8**
Cultural services			
Amenity value to property owners	1 586.8	18 200.0	23 660.0
Tourism value	2 400.0	27 527.8	35 786.1
Sub-total	**3 986.8**	**45 727.8**	**59 446.1**
TOTAL	**4 171.8**	**47 849.5**	**62 102.8**

The values associated with natural and semi-natural open space provide more of an understanding as to how residents in different areas value open space and these results suggest that city planners and developers need to consider the spatial context of open space areas and how best to provide and protect these areas across the EMA. The condition of the natural open space areas in the EMA is extremely important, and was found to have a significant influence on amenity value in particular. The study found that residents in the EMA are willing to pay for access to or views of open space, but only when these areas are in good condition. The results have also shown that residents attach a higher amenity value to urban parks than they do to natural open space. It is assumed that this is due to the many recreational opportunities that parks offer, such as jogging or playing football, activities that cannot be done easily in natural, densely vegetated areas, and also due to the fact that residents seek a safer and more easily accessible environment in which to enjoy open space in the city.

In contrast to amenity values, provisioning services are largely only significant in the peri-urban and rural areas of the EMA. The substantial area of rural landscapes around the urban edge, much of which are communal lands under the ownership of the traditional authority, deliver important provisioning services to the large numbers of poor households residing in the relatively dense settlements in these areas. Within the urban edge, the large natural areas tend to be under private ownership or state protection. The value of these services is highest in the outer-west and southern extents of the municipality where there are still large tracts of natural vegetation, such as woodlands and forests. In these areas, outside of the urban edge, there is a significant proportion of the population that relies on natural resources. The provisioning value in the northern area of the EMA and in the urban core tends to be considerably lower and largely restricted to the river systems and wetlands in these areas.

If urbanisation is properly managed, the spatial disjunct of provisioning and amenity values is likely to track the future growth of the city and lead to the increased value of the remaining open space areas. If not properly managed, a dead zone could be created at the city's periphery in terms of ecosystem services, and valuable opportunities will be lost. As Durban grows and the peri-urban areas become densely populated and urbanised, it is likely that the provisioning services provided by those landscapes will make way for amenity services to future urban inhabitants, as the demands of urban inhabitants replace those of the former rural inhabitants. Both within the planned urban edge and beyond, informal and rural settlements will continue to grow and densify, and the city will continue to be under pressure to provide housing for the poor for some time to come. It will be important to consider the implications of how this growth is allowed to happen. The findings of this study suggest that remnant green open space areas become increasingly valuable with urbanisation and increasing incomes. Thus ensuring the protection of key open space areas in the areas being settled would secure potentially valuable sources of amenity and spiritual and physical wellbeing for these future communities.

The role and spatial variation of regulating services is particularly interesting. Carbon storage is the most important of these services from a local economy perspective, and is also important from an international perspective. This value and the global value should be taken into consideration in South Africa's and eThekwini Municipality's commitments to combating climate change. The value of agricultural support services is modest, due to the relatively small extent of activities that benefit from this service. These are also generally outside of the urban edge. The nursery service of estuaries (Table 6.2), which supports the fisheries sector, is comparatively large. The fisheries that are supported include both recreational and small-scale commercial fisheries within and beyond the coastal areas of the EMA, though the majority of these beneficiaries are likely to reside within the EMA.

Three of the regulating services described are related to catchment hydrology. The capacity to perform these services tends to be greatest in the surrounding rural landscapes because of their location and size, but the beneficiaries of these services are downstream, and the value of hydrologic services is also dictated to a large extent by the location of infrastructure. Thus the spatial variation of these services was more irregular in relation to the urban edge than for provisioning and amenity services (Figure 6.1 through 6-3). The values of these services were found to be highest upstream of Inanda and Hazelmere Dams in the northern and outer-west areas of the EMA, where sediment retention and water quality amelioration were most valuable, and also in the catchments of the downtown and harbour areas, where flood attenuation was highly valuable. Within the lower urban areas, however, hydrologic-related services tend to have been overwhelmed to the extent that they can no longer ameliorate the increased run-off and pollution from urban areas to a significant extent. This is a general reality of urban systems which is increasingly being addressed through innovative engineering solutions. Indeed regulating services are one area where technological innovation does show promise of being able to augment or replace ecosystem services, and where increased efficiency may be also desirable to protect the supply of ecosystem services from aquatic ecosystems that, unlike terrestrial systems, are more certain to remain in place, in one form or another. The optimal balance between relying on the services provided by natural capital versus implementing engineering solutions to neutralise the effects of urbanisation on run-off and water quality is explored in more detail in the accompanying report (Turpie et al. 2016).

Very few comprehensive studies have quantified and spatially evaluated the benefits supplied by urban ecosystems (Elmqvist et al. 2015). Although this was a desktop assessment which still has substantial room for improvement and refinement through further research, it represents the most comprehensive assessment of ecosystem services within an urban environment in Africa to date, and one of perhaps only a handful in the world.

Overall, the study shows that the ecosystem services profile of an urban area is very different from that of non-urban landscapes or regional level assessments. While natural and semi-natural ecosystems within the study area provide a full suite of ecosystem services, the value is dominated by amenity services to residents and visitors, both of which make a considerable and tangible contribution to Durban's economy. Even so, the estimate of amenity value does not capture all of the recreational, spiritual and health benefits associated with of green open space, since estimating these values requires further data collection.

The findings of this study can be used to identify priority areas for supply of ecosystem services and will be useful for decision-making processes related to understanding the tradeoffs between spatial development and conservation. This is pertinent to both environmental and strategic development planning within the eThekwini Municipality in in forming the development of a thriving, resilient city. While the study focuses on ecosystem services, it is important to note

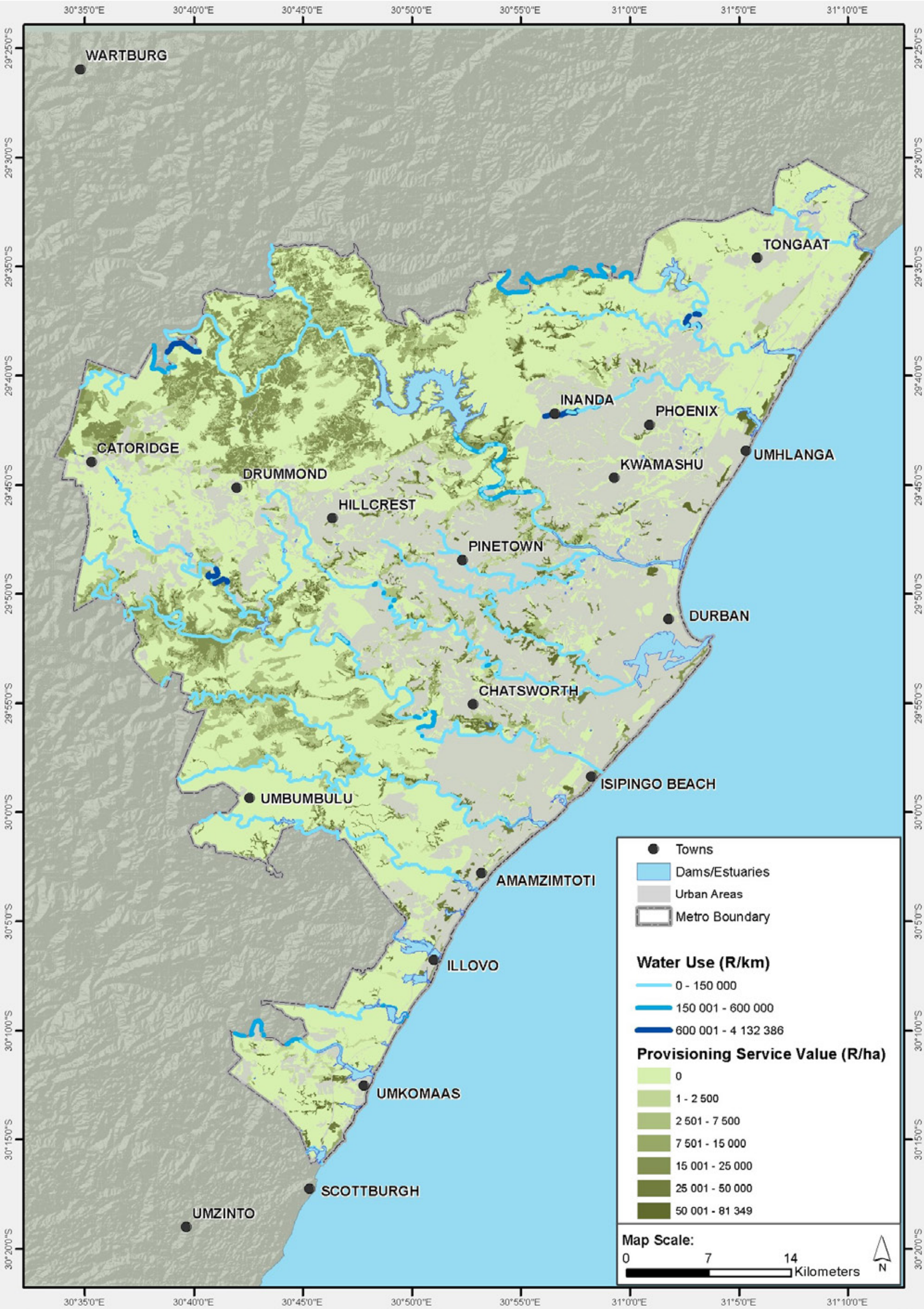

Figure 6.1 Summary of the provisioning, regulating and cultural service values (NPV) associated with natural and semi-natural open space in the EMA, excluding estuary provisioning and regulating services.

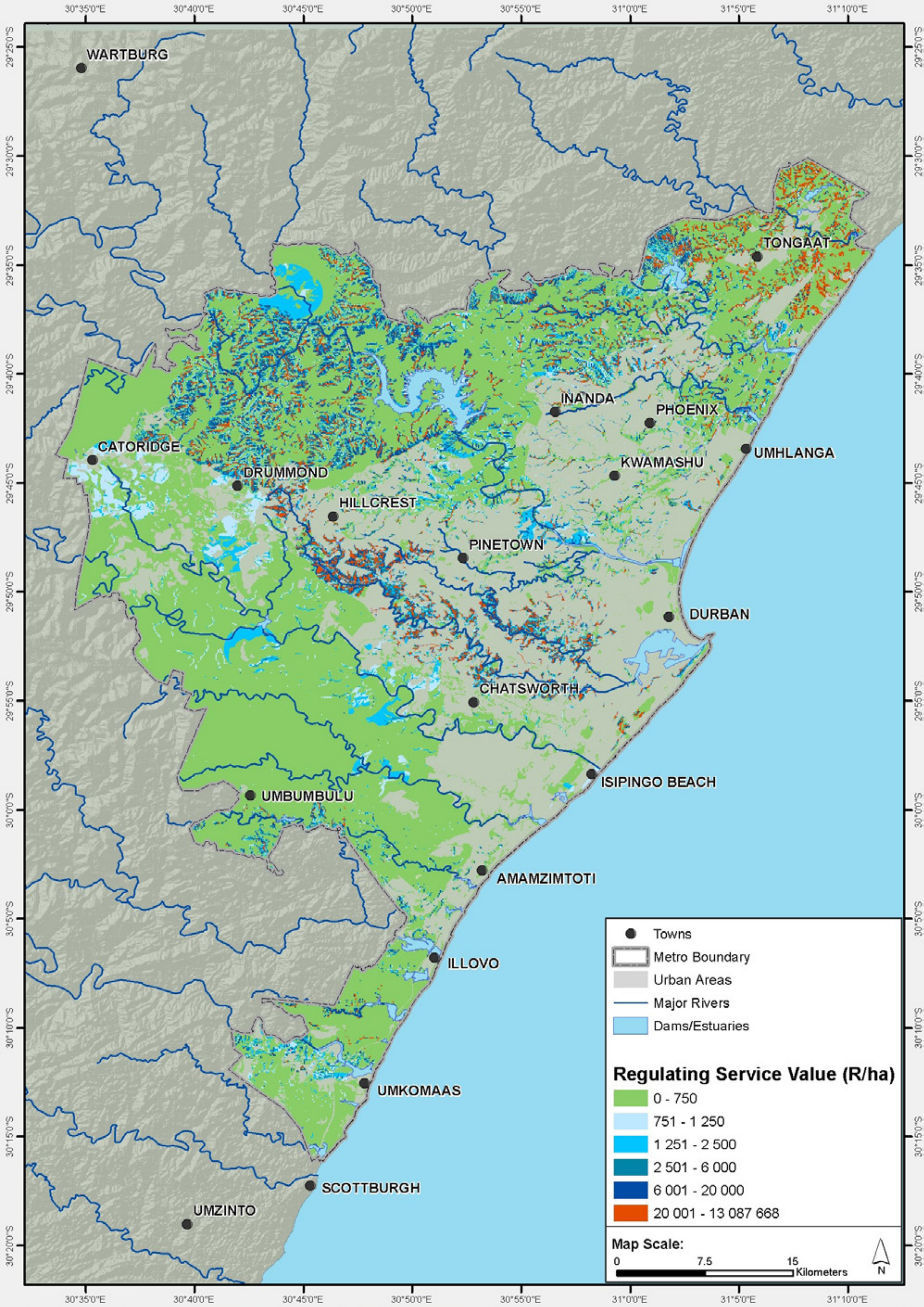

Figure 6.2 Summary of the provisioning, regulating and cultural service values (NPV) associated with natural and semi-natural open space in the EMA, excluding estuary provisioning and regulating services.

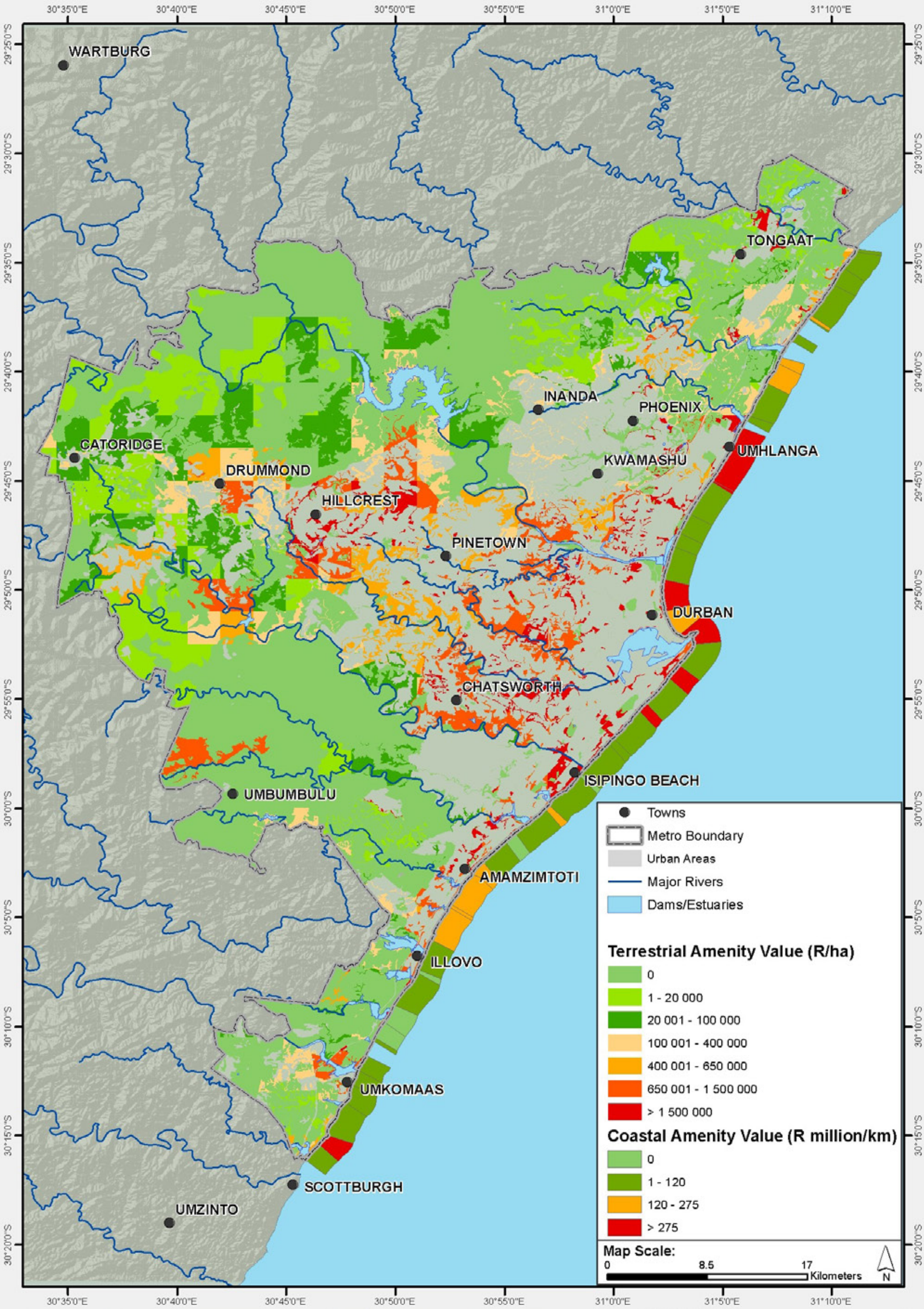

Figure 6.3 Summary of the provisioning, regulating and cultural service values (NPV) associated with natural and semi-natural open space in the EMA, excluding estuary provisioning and regulating services.

that it does not provide a full estimate of the value of biodiversity per se. Our study does not capture the existence value and some of the other intangible, cultural values attached to biodiversity, nor does it adequately capture the role of species richness and community structure on the capacity of ecosystems to supply ecosystem services. This is a shortcoming of most valuation studies, and it is for this reason that conservation and planning decisions cannot be made on the basis of economic values alone. Planning should also incorporate biodiversity targets that are determined on the basis of their intrinsic value and understood role in maintaining ecosystem integrity and resilience.

Table 6.2 Summary of the provisioning and regulating service values (NPV, 20 y, 6%) associated with estuaries in the EMA (R millions)

Estuary	Provisioning Services (subsistence fisheries)		Regulating Services (nursery value)	
	NPV @ 6%	NPV @3%	NPV @ 6%	NPV @3%
uTongati	-	-	0.4	0.5
uMdloti	7.1	9.2	2.7	3.6
oHlanga	6.9	9.0	1.7	2.2
uMngeni	7.8	10.1	17.9	23.3
Durban Bay	9.8	12.7	63.6	82.7
iSiphingo	-	-	0.3	0.4
eziMbokodweni	-	-	1.4	1.8
aManzimtoti	-	-	0.6	0.8
Little aManzimtoti	-	-	0.2	0.3
iLovu	7.8	10.1	9.6	12.5
uMsimbazi	6.5	8.5	7.1	9.2
uMgababa	6.8	8.8	5.6	7.3
Ngane	1.2	1.5	0.5	0.7
uMkhomazi	7.1	9.2	14.9	19.4
uMahlongwane	4.6	5.9	1.9	2.5
iMahlongwa	6.4	8.3	1.8	2.3
TOTAL	**71.8**	**93.4**	**130.8**	**169.3**

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APPENDIX 1. ECOSYSTEMS AND BIODIVERSITY OF THE EMA

A1.1 Terrestrial ecosystems

A1.1.1 Introduction

This section describes the extent, biodiversity attributes, location and abundance of natural resources found in terrestrial ecosystems across the EMA. There is very limited historical research for a number of terrestrial taxa, such as invertebrates, mammals, amphibians and reptiles, with most studies focusing on a few focal taxa and records of the distribution and occurrence of species within the EMA being incidental coming from private collections and museums (EPCPD 2012). More information is available for plants and birds which have been studied in more detail across the EMA.

A1.1.2 Vegetation types

A variety of forest, woodland, bush and grassland habitats are found in the EMA (Table A1. 1). Almost all of these have been significantly transformed, are threatened and in need of protection, with several being critically endangered (Table A1. 1; SDF 2014, SANBI; EPCPD 2012).

Table A1.1 The vegetation types (KwaZulu-Natal and SA) found within the EMA and their conservation status as used by eThekwini Municipality and SANBI (Source: EPCPD Spatial Conservation Plan 2012)

SA Vegetation Type	KwaZulu-Natal Vegetation Type	Conservation Status (eThekwini Municipality)	Conservation Status (National)
Ngongoni Veld	Dry Ngongoni Veld	Endangered	Vulnerable
	Moist Ngongoni Veld	Critically Endangered	
Eastern Valley Bushveld	Eastern Valley Bushveld	Near Threatened	Least Threatened
KwaZulu-Natal Hinterland Thornveld	KwaZulu-Natal Hinterland Thornveld	Vulnerable	Vulnerable
KwaZulu-Natal Sandstone Sourveld	KwaZulu-Natal Sandstone Sourveld	Critically Endangered	Endangered
KwaZulu-Natal Coastal Belt	North Coast Bushland	Critically Endangered	Endangered
	South Coast Bushland	Endangered	
	North Coast Grassland	Critically Endangered	
	South Coast Grassland	Critically Endangered	
Scarp Forest	Southern Coastal Scarp Forest	Vulnerable	Least Threatened
Northern Coastal Forest	KwaZulu-Natal Coastal Forest	Endangered	Least Threatened
	KwaZulu-Natal Dune Forest	Critically Endangered	
Mangrove Forest	Mangrove Forest	Critically Endangered	Critically Endangered
Swamp Forest	Voacanga thouarsii Swamp Forest	Endangered	Critically Endangered

As part of the eThekwini Municipality Spatial Conservation Plan the national, regional and local extent (ha) of the different vegetation types were listed with estimated original extents, current levels of transformation and remaining areas within the EMA classified according to their condition as assessed for the EMSCP (Table A1. 2). Table A1. 2 highlights the extent of transformation for each vegetation type and the levels of degradation within the EMA. For example, 77% and 72% of the North and South Coast Grassland have been transformed in the EMA respectively, and of the remaining untransformed grassland 52% of it is considered to be degraded (Table A1. 2). General descriptions for each vegetation type are given below and include information about extent, levels of transformation and land use based on data and information presented in the EMSCP (2012).

Table A1.2 The vegetation types (KwaZulu-Natal and SA) found within the EMA and their conservation status as used by eThekwini Municipality and SANBI (Source: EPCPD Spatial Conservation Plan 2012)

	Original Extent (ha)			Transformed		% Condition of untransformed (EMA)		
	KwaZulu-Natal	EMA	EMA (%)	KwaZulu-Natal (%)	EMA (%)	Good	Inter.	Degr.
Dry Ngongoni Veld	268 024	18 109	7	73	33	69	7	23
Moist Ngongoni Veld	442 424	12 394	3	83	31	33	9	58
Eastern Valley Bushveld	291 207	20 080	2	?	19	68	6	26
KwaZulu-Natal Hinterland Thornveld	113 341	6 824	6	?	32	80	3	16
KwaZulu-Natal Sandstone Sourveld	160 819	15 681	10	?	67	61	10	29
North Coast Bushland	88 811	32 758	37	79	44	32	15	53
South Coast Bushland	89 103	1 953	2	71	37	12	33	55
North Coast Grassland	291 877	82 979	28	95	77	22	27	52
South Coast Grassland	153 568	24 184	16	94	72	19	29	52
Southern Coastal Scarp Forest	33 750	8 878	26	NA	NA	85	14	1
KwaZulu-Natal Coastal Forest	21 089	2 193	10	NA	NA	59	36	4
KwaZulu-Natal Dune Forest	12 396	1 287	10	NA	NA	80	12	9
Mangrove Forest	2 297	65	3	NA	NA	100	0	0
Voacanga Swamp Forest	3 022	55	2	NA	NA	87	6	7

Ngongoni Veld
Within the EMA Ngongoni Veld is found inland from the upper uMngeni catchment in the north to the upper iLovu catchment in the south and can be found at elevations of 180-870 metres above sea level. This ecosystem is characteristically species-poor due to the dominance of the tall grass Aristida junciformis. Within KwaZulu-Natal there are two vegetation types found within this group, namely Dry and Moist Ngongoni Veld. Regionally both of these ecosystems are highly transformed and of the remaining extent of the Ngongoni Veld in the EMA just more than one third has undergone some form of transformation (EPCPD 2012).

Of the untransformed areas of Ngongoni Veld in the EMA, 60% is located in traditional authority areas, 18% is under formal town planning schemes and 22% is designated for non-scheme agricultural areas (EPCPD 2012). There are no Ngongoni Veld areas that are formally protected in the EMA (EPCPD 2012).

Eastern Valley Bushveld
This vegetation type is generally confined to deeply incised river valleys with plant communities dominated by semi-deciduous woody species and succulent species. Within the EMA Eastern Valley Bushveld is confined to the upper reaches of the uMngeni and Umlaas Rivers occurring between 100-800 metres above sea level. The areas where this vegetation is predominantly found are steep resulting in low levels of transformation with less than a third having been transformed and of the remaining habitat the majority still in a good condition (EPCPD 2012). Of the untransformed areas of Eastern Valley Bushveld in the study area 99% is found in traditional authority areas and only 1% is covered by formal planning schemes. There are no areas of this vegetation that are formally protected in the EMA (EPCPD 2012).

KwaZulu-Natal Hinterland Thornveld
KwaZulu-Natal Hinterland Thornveld is usually situated upslope from Eastern Valley Bushveld in steep river valleys and is intermediate in its characteristics between this type of vegetation and Ngongoni Veld where there are exchanges of common biota (EPCPD 2012). It is characterised by open thornveld dominated by Acacia species. Within the EMA this vegetation is limited to the upper catchments of the uMngeni and Umlaas Rivers occurring between 300-825 metres above sea level. It is estimated that roughly one third of KwaZulu-Natal Hinterland Thornveld has been transformed with 80% of the remaining areas being in a good condition. The steepness of the localities and lack of any vehicular access contributes preventing any further transformation. Untransformed areas of this type of vegetation are located predominantly in traditional authority areas (68%) and some in non-scheme agricultural areas (30%). Only a small portion (2%) is under formal planning schemes. There are no areas of this vegetation that are formally protected in the EMA (EPCPD 2012).

KwaZulu-Natal Sandstone Sourveld
This vegetation type is typically species rich with high levels of forb diversity and high rates of plant endemism (EPCPD 2012). Woody species are generally fire tolerant such as Protea species and low shrubs. Within the EMA KwaZulu-Natal Sandstone Sourveld tends to be found in insular pockets from Inanda Mountain in the north to Umbumbulu in the south, usually between 130-870 metres above sea level (EPCPD 2012). This vegetation type is classified as Critically Endangered and has experienced significant transformation across its range with more than two thirds of its original extent transformed. The remaining areas of KwaZulu-Natal Sandstone Sourveld continue to be under further threat with 29% in a degraded state as a result of unmanaged fire regimes and the spread of alien invasive plant species (EPCPD 2012). Only 1% of the original distribution of this vegetation type is formally protected in the EMA in Krantzkloof Nature Reserve (EPCPD 2012).

KwaZulu-Natal Coastal Belt
The KwaZulu-Natal Coastal Belt exists in a dissected and rolling landscape which in the past would have consisted of a mix of coastal forest, grassland and woodland plant communities. Within the EMA this habitat is located along the entire coastal plain between sea level and 660 metres above sea level. There are four vegetation types classified within the KwaZulu-Natal Coastal Belt, namely North Coast Grassland, South Coast Grassland, South Coast Bushland and North Coast Bushland. All of these vegetation types are found in the most highly transformed areas of KwaZulu-Natal and as a result have become highly impacted and threatened. North and South Coast Grassland are considered to be particularly important for the EMA as more than two-thirds of their original extent was located within the boundaries of the EMA (EPCPD 2012). Untransformed areas have also become highly degraded and there are very few original patches remaining. More than half of the remaining areas are located in traditional authority areas (52%) and the rest in formal planning schemes (30%) and non-scheme agricultural areas (18%). Within the EMA only North Coast Bushland and North Coast Grassland are formally protected, and these areas make up less than 1% of their original extent in the EMA (EPCPD 2012).

Scarp Forest
Scarp Forests are species rich, have high levels of endemicity and tend to be found in steep gorges and scarps. They are transitional in nature between Afromontane and Coastal Forests characterised by species from both of these vegetation types. Scarp Forest is structurally tall with high basal area and woody stems, low levels of multi-stemming and a poor herb layer (EPCPD 2012). Within the EMA these forests are highly fragmented but occur predominantly inland of 4km from the coast between 300-875 metres above sea level.

Scarp Forest has been highly exploited in the EMA for natural resources such as medicinal plants and various building materials. However, there are still some good quality patched remaining in areas that are less accessible (EPCPD 2012). The remaining Scarp Forests are located in traditional authority areas (44%), formal planning schemes (35%) and non-scheme agricultural areas (21%). Of the remaining forest, only 6% (531 ha) is formally protected in the Krantzkloof, North Park, Kenneth Stainbank and Palmiet nature reserves (EPCPD 2012).

Northern Coastal Forest

Coastal Forests are medium to tall forests with low basal area of woody stems, high levels of multi-stemming and a well developed herb layer (EPCPD 2012). In the EMA these forests are located along the entire coastline on the undulating coastal plain from the dunes to approximately 580 metres above sea level. Northern Coastal Forest is made up of two forest types; KwaZulu-Natal Coastal Forest and KwaZulu-Natal Dune Forest. KwaZulu-Natal Dune Forest occurs largely along the border of the dunes beyond the salt spray zone (EPCPD 2012) and has become highly fragmented as a result of coastal development. It is classified as Critically Endangered. Approximately 60% of the remaining Dune Forest area is in formal planning schemes (open space, residential and amenity), 34% in non-scheme agricultural areas and 6% in traditional authority areas. Only 2% of Dune Forest is formally protected in the Umhlanga Lagoon Nature Reserve and Beachwood Mangroves Nature Reserve. Of the remaining untransformed KwaZulu-Natal Coastal Forest, 56% is within formal planning scheme areas (residential, open space and utility), 28% is in non-scheme agricultural areas and 16% is in traditional authority areas. Only about 1% of the Coastal Forest is formally protected in the Happy Valley Nature Reserve.

Mangrove Forest

Mangroves are typically limited to the intertidal areas of permanently open estuaries and are species poor usually consisting of one to three dominant species of mangrove tree (EPCPD 2012). Mangroves are able to tolerate a wide range of conditions that they are subjected to in the intertidal zone. The forests are structurally simple with a limited vertical variation when compared to terrestrial forest types. In the EMA mangrove stands are located in three estuaries; Isipingo, Durban Bay (Bayhead) and uMngeni (Beachwood). Approximately 97% of mangrove area in Durban Bay has been lost since the beginning of the twentieth century and the current extent in this estuarine bay is 14 ha. Similarly in Isipingo there has been a significant reduction in mangroves as a result of residential and industrial development in the area and the associated diversions of the Umlaas and Isipingo rivers (EPCPD 2012). All three remaining mangrove stands fall within the formal planning scheme zoned for open space (62%) and utility (22%). Approximately 72% of mangroves are formally protected in the EMA in the Beachwood Mangroves Nature Reserve (EPCPD 2012).

Swamp Forest

Swamp Forests are grow in waterlogged soils and are medium height forests with well-developed canopy layers and a poorly developed understorey layer (EPCPD 2012). Within the EMA Swamp Forest is located in only a few small fragments in four localities in the central and southern planning regions occurring between 140-530 metres above sea level (EPCPD 2012). Only a small portion (55ha) is found within the EMA and surprisingly most of the areas are reported to be in a good condition despite occurring in very populated regions of the EMA. Most of the remaining Swamp Forest is situated in traditional authority areas (71%) and commercial farming areas (25%) and only a small portion (4%) is in formal planning schemes. The latter being Glenholme Private Nature Reserve that is zoned for open space (EPCPD 2012).

A1.1.3 Plants

There is high plant diversity within the EMA with a total of 2267 species recorded from 204 different plant families (EPCPD 2012). This represents more than half the known families found in South Africa. Endemicity is also high in the EMA with 379 species, 16% of the total, being classified as South African endemics (EPCPD 2012). Biogeographically the plant species in the EMA are made up of a large tropical and subtropical component, a smaller temperate component and a localised endemic group (EPCPD 2012).

A total of 180 plant species significant for conservation in the EMA were assessed during the EMSCP process and of these 31 were classified as threatened, including 11 Endangered and seven Critically Endangered species. Of those that are Critically Endangered only three species are known to have existing populations in the EMA with the remaining four species not recorded in the EMA for decades and assumed to be locally or globally extinct (EPCPD 2012). A significant proportion of the plant species are classified as being rare and although they are not yet threatened, localised and unregulated pressures in the EMA could impact on these species too. The rare status of these species has been driven by habitat displacement, habitat degradation and the direct exploitation of some species for medicinal purposes, fuelwood and construction purposes (EPCPD 2012).

A1.1.4 Mammals

A total of 82 mammal species have been recorded in the EMA and of these three are alien and five of the larger mammals have been reintroduced in the area (EPCPD 2012). Historically the EMA was inhabited by a number of large mammal species that are now locally extinct, such as elephant, lion, buffalo, leopard, hippopotamus and spotted hyena (EPCPD 2012). Detailed mammal data in the EMA is limited, however the EPCPD (2012) Spatial Conservation Plan outlined the current status of some of the known mammal species and the most common threats to these species.

Threatened species included two bats, Kerivoula argentata and Otomops martiensseni that were classified as Endangered and Vulnerable respectively. Kerivoula argentata, the Damara woolly bat, is insectivorous and has its southern most distribution records in the EMA, however record are outdated and its current extent is not known (EPCPD 2012). Otomops martiensseni, the large-eared free-tailed bat has a highly disjointed population within the EMA with its nearest known populations being in Zimbabwe and Madagascar and as a result has been recognised as an evolutionary significant species in the EMA (EPCPD 2012). There are two threatened species of antelope that occur in the EMA, the Oribi, Ourebia ourebia, and the Blue Duiker, Philantomba monticola, which are classified as Endangered and Vulnerable respectively. Both these antelope species are under significant pressure in the EMA as a result of fragmented populations, illegal hunting and other anthropogenic influences (EPCPD 2012). There are five bat species and two rodent species that have their southernmost distribution records in the EMA with one species in particular the Angoni vlei rat, Otomys angoniensis, is considered an indicator of ecosystem health due to its association with wetlands (EPCPD 2012). Other mammals found in the EMA include mice, rats, servals, weasels and shrews.

A1.1.5 Birds

A total of 526 bird species have been recorded in the EMA (EPCPD 2012) and of these at least 13 species have gone locally extinct, including Saddle-billed Stork, Lesser Flamingo, Greater Flamingo, Black Heron, Chestnut-banded Plover, Southern Banded Snake-Eagle, Swamp Nightjar, Eastern Bronze-naped Pigeon, Ground Woodpecker, Black Coucal, Blue Swallow, Knysna Warbler and Rosythroated Longclaw. Most of these local extinctions are a result of habitat degradation and transformation (EPCPD 2012). The EPCPD (2012) broadly classified the bird species into the following biogeographic groups:

- A tropical group of widespread species that are mostly resident throughout the year;
- Southern African seasonal migrants, mostly of a more temperate origin, including altitudinal migrants and migrants from the south western regions of South Africa;
- African migrants from the tropical regions of the continent; and
- Palearctic migrants from Eurasia.

Of the bird species assessed and used in the EPCPD (2012) Spatial Conservation Plan 12 were classified as threatened including two Endangered species, the Spotted Ground-Thrush and the Black-rumped Buttonquail. The Spotted Ground-Thrush is a forest specialist that migrates into southern KwaZulu-Natal from the Eastern Cape over the winter months and the forests within the EMA make up a significant proportion of its non-breeding habitat (EPCPD 2012). Rates of endemism in the selected species were found to be low with only two species being near endemics to South Africa; the Bush Blackcap, a non-breeding migrant, and the Knysna Turaco. There are four species that have their southernmost distributions within the EMA and a further two species that have distributions that terminate just south of the EMA boundary (EPCPD 2012). A number of birds found within the EMA are indicators of ecosystem health, the majority of these are waterbird species that are found only in a particular type or condition of habitat that they use. There are specific raptors and owls that are also used to assess ecosystem health due to their high trophic position, including the Fish Eagle, African Marsh Harrier, Martial Eagle, and Lanner and Peregrine Falcons (EPCPD 2012).

A1.1.6 Reptiles

A total of 69 reptile species have been recorded within the EMA including 26 lizards, 42 snakes and two terrapins (EPCPD 2012). However, many of the records for these species predate the 1990's and the lack of current up to date data means many of these species may no longer occur in the EMA. One snake species, a harmless blind snake, Rhamphotyphlops braminus is an alien invasive species unintentionally introduced into the EMA some time before 1985 (EPCPD 2012). There are two species classified as threatened, the Natal rock python which is Vulnerable and Smith's dwarf burrowing skink which is Endangered. Smith's dwarf burrowing skink has a very restricted distribution and is endemic to the EMA, found only from the mouth of the uMngeni River south to Amanzimtoti covering approximately 431km2 (Broadley 2010). It is found in sandy soils of coastal thicket, grassland and dune forest from Berea Red Sands from the Canelands in the north to Clansthal in the south, and only 10% of its known habitat is formally protected (Broadley 2010, EPCPD 2012). Endemic to KwaZulu-Natal and with most of its range in the EMA, the black-headed dwarf chameleon, Bradypodion melanocephalum, is a flagship species for the EMA and is predominantly found in coastal habitat (EPCPD 2012). The ranges of both Smith's dwarf burrowing skink and the black-headed dwarf chameleon intersect some of the most developed coastal areas of the EMA where habitat transformation and degradation is high (Broadley 2010, EPCPD 2012).

Other notable species include those that reach their southernmost distribution in the EMA; the Natal purple glossed snake and the Nyasa file-snake and two species that are indicators of ecosystem health within the EMA; the Natal black water-snake (riverine) and the green mamba (dune forest) (EPCPD 2012).

A1.1.7 Amphibians

There are a total of 37 amphibian species recorded in the EMA, however five of these species have not been recorded since 1996 and are considered to be locally extinct (EPCPD 2012). Amphibians are very sensitive to changes in their surroundings, especially to anthropogenic influences in urban environments such as water and air pollution, habitat degradation, isolation, pathogens and climate change (Hamer & McDonnell 2008).

The Kloof frog, Natalobatrachus bonebergi, is listed as Endangered and its numbers are thought to be further decreasing as a result of habitat loss, exploitation and pollution (SA-FRoG & IUCN 2012). This species is found in pristine forested gorges where it is usually found along streams, where it breeds (EPCPD 2012, SA-FRoG & IUCN 2012). Its habitat in the EMA is becoming increasingly threatened by water pollution and over-exploitation of forested areas (EPCPD 2012). Another species of concern is the spotted shovel-nosed frog, Hemissus guttatus, which has its southern most records in the EMA and is listed as Vulnerable (SA-FRoG & IUCN 2010). It occurs in wooded and open habitat adjacent to wetlands, seasonal pans, swampy areas and pools near rivers (SA-FRoG & IUCN 2010).

A1.2 Rivers and Wetlands

A1.2.1 Introduction

Rivers and wetlands provide a wide range of ecosystem goods and services such as drinking water, fish, flood attenuation and water purification. There is little information about natural resource use in freshwater systems within the EMA, however there is information about the goods and services provided by wetlands and rivers and use of these in other areas of KwaZulu-Natal. There is also a general lack of fine scale biodiversity data for the rivers and wetlands of the EMA (EPCPD 2012) and most of the available information has focused around the health of the river systems and habitat type data collection. Ground Truth (2006) conducted a study on the state of the rivers in the EMA providing health status data for 33 rivers and streams. The health status for each river was assessed based on bioindicators such as habitat integrity, water quality, plant communities and invertebrate assemblages. The rivers and wetlands of the EMA fall into the Mvoti – Umzimkulu Water Management Area (WMA) and the status quo assessment and delineation analysis report (DWA 2013a) provides some detailed information about the tertiary catchments and their associated rivers and wetlands.

Freshwater systems in the EMA are under increasing threat from impacts such as flow modification, sand mining and pollution from industrial and sewage effluent. Unplanned and extensive informal settlement development in the upper catchment areas is also having a large impact on these systems.

A1.2.2 Rivers

Within the EMA there are 18 river catchments and all the rivers located in the EMA fall into the Mvoti – Umzimkulu WMA. This WMA consists of eight tertiary catchments of which four are included in the eThekwini Municipality; the uMdloti, uMngeni, uMlazi and iLovu, and uMkhomazi tertiary catchments (Figure A1. 1, DWA 2013a). The main river systems found in these tertiary catchments and in the EMA are the uMkhomazi, uMngeni, uMdloti, oHlanga, uTongathi, uMlazi, Mbokodweni and iLovu. The larger river systems originate in the Drakensberg Mountains, the medium rivers in the KwaZulu-Natal Midlands and the smaller rivers close to the coast (DWA 2013a).

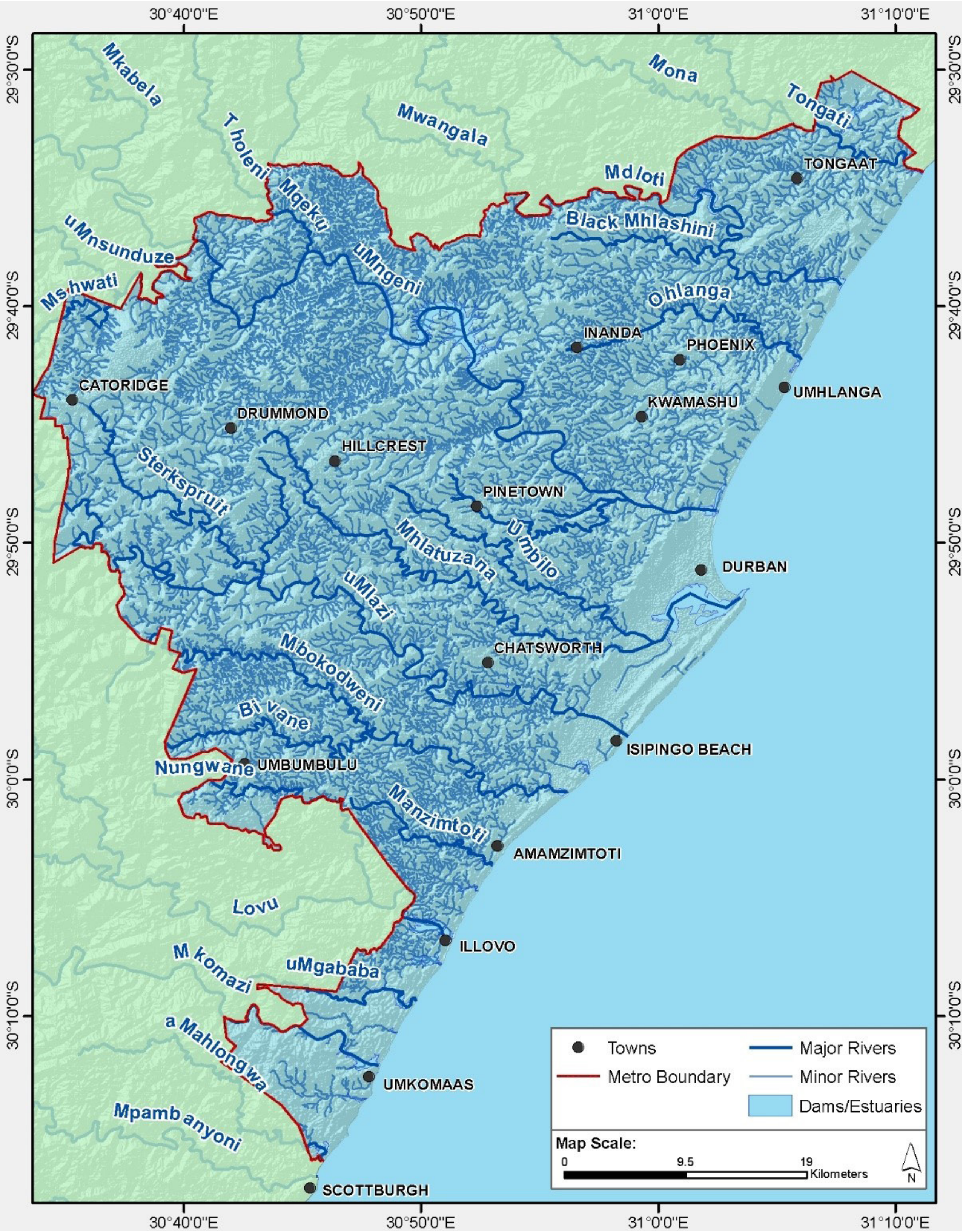

Figure A1.1 The major and minor rivers found within the EMA

uMdloti tertiary catchment

The uMdloti tertiary catchment includes the uMdloti, uTongathi and oHlanga Rivers. There are two major dams on these rivers within the EMA; the Hazelmere Dam on the uMdloti River and the smaller Dudley Pringle Dam on the Tongati River. Land use in this catchment consists mainly of dryland and irrigated sugarcane, predominantly on communal land (DWA 2013a). The small urban centres of Tongaat, Umhlanga and Verulam are located within this catchment. The water quality of the rivers in this catchment are generally poor as a result of point source pollution, especially along the coastal strip which is highly developed. Impacts both above and below Hazelmere Dam on the uMdloti River include pollution from informal settlements, subsistence agriculture and animal grazing.

Numerous Waste Water Treatment Works (WWTW) discharge into the uMdloti and Tongati Rivers from Phoenix, Umhlanga, Tongaat and the King Shaka International Airport WWTWs (DWA 2013a) affecting both the flow and water quality of the rivers. There are a number of low density rural settlements spread throughout the catchment.

uMngeni tertiary catchment

The uMngeni River system is largely regulated and developed (DWA 2013a). This river functions as the main source of water for the Durban to Pietermaritzburg area and is serviced by four major dams; Midmar Dam, Nagle Dam, Albert Falls Dam and Inanda Dam. However, Inanda Dam is the only one falling within the eThekwini Municipal boundary. Water quality in the lower uMngeni is generally poor as a result of the dense human population in and around Durban. A vast number of informal settlements found along this river system are not serviced with adequate sanitation resulting in point source pollution contributing to poor water quality.

The area above Inanda Dam is largely rural with some subsistence agriculture activities and dryland sugarcane and forestry. The lower uMngeni River below Inanda Dam is considered to be in a particularly poor state as a result of flow regulation and extensive urban and industrial areas. The Palmiet River located below the dam is also in a poor state as a result of impacts from industrial and urban developments along this stretch of river. Discharges from WWTW into the uMngeni and associated tributaries, such as the Umhlangane River, also contribute the poor health of this system.

uMlazi & iLovu tertiary catchment

This catchment is dominated by irrigation agriculture and afforestation and is largely unregulated (DWA 2013a). The main rivers associated with this catchment are the uMlazi, iLovu, Mhlatuzana, Mbokodweni and Umbilo. The Shongweni Dam on the uMlazi River has silted up and is now only used for recreational and educational purposes (DWA 2013a). Generally the water quality in the catchment is poor, especially the uMlazi River.

Upstream of the Shongweni Dam, the uMlazi river catchment is impacted by changes to flow from farm dams and irrigation and non-flow impacts such as invasive alien plants, and point source pollution from forestry, agriculture and settlement activities. Low density settlements, semi-urban and industrial areas are located in the lower half of the upstream section and discharges from the Hopewell and Hammersdale WWTW into the river systems contribute to the poor water quality found in this area (DWA 2013a). The lower uMlazi is in a poor state due to degraded water quality and riparian vegetation removal as a result of animal grazing and wood harvesting by communities living along this stretch of river. Discharges from WWTW in this section of river affects both the flow and the wwater quality of the river and there is a hazardous landfill site in the upper reaches of the tributaries that affects water quality. The lower end of the uMlazi River is canalised and therefore there is no estuary (DWA 2013a).

There are no dams on the Mbokodweni River. The upper and middle reaches are dominated by some dryland sugarcane farming and are occupied by scattered rural villages. The middle to lower areas are dominated by semi-urban and urban areas (uMlazi and Isipingo) as well as industrial areas by the coast. Discharges from WWTW in the lower reaches also impact water quality of this river negatively.

The upper iLovu catchment is situated in an area with extensive forestry and sugarcane and rural areas with high density townships, all of which have contributed to the poor water quality found in these rivers. The coastal rivers (Umsimbazi, uMgababa, Manzimtoti, Little Manzimtoti) associated with the iLovu catchment are also mostly in a poor state with rural settlements, development and agricultural activities contributing to poor water quality.

The Mhlatuzane and Umbilo Rivers, located upstream of Durban Bay, and the Sipingo River located south of Durban Bay, are highly developed and are surrounded by industrial and urban development. The main impacts include sedimentation, solid waste pollution, effluent run-off, alien vegetation and the removal of riparian vegetation.

uMkhomazi tertiary catchment

Forestry and dryland sugarcane farming are the predominant activities in this catchment. The upper Mkomazi River is located outside of the EMA with only a small section of the middle reaches and all of the lower reaches located within the EMA in the southern planning region. Low density rural settlements are found in the middle to lower reaches and land use activities include community water use, grazing, subsistence agriculture and riparian vegetation removal for wood and grazing. High levels of sedimentation from forestry and agricultural activities occur throughout this catchment. At the mouth of the uMkhomazi River approximately 44 million m3 per annum of water is abstracted by SAPPI-SAICCOR (DWA 2013a).

A1.2.3 Wetlands

Wetlands are highly variable systems and range from permanently wet shallow lakes to periodically wet valley bottoms (eThekwini Municipality 2011). In the EMA there are typically five hydrogeomorphic wetland types:

- Channelled valley bottom wetlands are situated in the bottom of a valley, have small channels and are fed by ground water from slopes and overbank flooding.
- Unchannelled valley bottom wetlands are situated in the bottom of a valley but have no channel and are fed by ground water and surrounding slopes.
- Floodplains are extensive flat areas that are usually on either side of a large river channel, fed by overbank flooding. There are usually oxbow lakes and meander scars present.
- Hillslope feeding a watercourse. These are wet patches that are located on a hill slope of hilltop rather than in a valley and there is a natural water course joining the system to other wetlands, streams or rivers.
- Hillslope not feeding a watercourse. These wetland patches are located on a hillside or hilltop that does not have any direct natural link to other wetlands, streams or rivers.

As a result of the undulating nature of the EMA, the most common wetland type are the valley bottom wetlands (eThekwini Municipality 2011). The largest wetlands in the EMA are the floodplains associated with the larger rivers such as the uMdloti, uMngeni and uMlazi, but they are also associated with some of the smaller rivers found in the EMA (eThekwini Municipality 2011). High priority wetlands with high conservation importance include those found on the Mdloti, uMngeni and oHlanga Rivers which are mainly floodplain and channelled valley bottom wetlands (DWA 2013a). These areas are characterised by unique, high diversity wetland types and high species richness (DWA 2013a). Wetlands with moderate importance and lower priority status are located on the Mkomazi, iLovu and Tongati and associated rivers and are mostly small, narrow valley bottom wetlands.

A number of biophysical drivers shape the structure, composition and functioning of wetland ecosystems and the vegetation that is found in these systems. These drivers include climate, geology, hydrology, water quality and geomorphology. Vegetation characteristically found in wetlands in the EMA include reeds such as the Common reed (Phragmites australis), rushes such as Bullrush (Typha capensis), certain species of water loving sedges, such as Giant sedge (Cyperus dives), Dwarf papyrus (Cyperus prolifer), and Finger sedge (Eleocharis dregeana), water loving grasses such as Wild rice grass (Leersia hexandra) and Rat tail drop seed grass (Sporobilis africana), certain swamp forest tree species such as Umdoni (Syzigium cordatum), Swamp fig (Ficus trichopoda) and Wild frangipani (Voacanga thouarsii) (eThekwini Municpality 2011).

There is one Critically Endangered species of frog found within the EMA. The Pickersgill's Reed Frog is endemic to KwaZulu-Natal coast of South Africa, with all of the southernmost records for the species found within the EMA (EPCPD 2012, Tarrant & Armstrong 2013). This frog is found in densely vegetated (reed-bed), stagnant valley bottom wetlands, which are also Critically Endangered, from the coast to approximately 200 metres above sea level (EPCPD 2012). The majority of the wetland habitat is located on privately or community owned land and is threatened by habitat degradation and coastal development (Tarrant & Armstrong 2013).

In the rural and traditional authority areas of the EMA local communities rely of wetlands for building and craft materials such as sedges and reeds. They also harvest certain tree materials, such as the fruits of the wild frangipani tree for medicinal purposes. Other plant materials harvested include the roots and seeds of grasses for food and flour, and stems, tubers, leaves and bark from other species for food, drink and medicinal uses. Wetlands are also important for water provision for communities that live in rural areas and do not have access to piped water. Water is used for household needs such as drinking water, bathing, washing of clothes and also for livestock. The fertile soils in and around wetlands are also used for the growing of food crops such as banana and madumbi (sweet potato). Details about the quantities and extent of natural resource use in wetlands in the EMA are not well known. Estimates of resource use were based on studies from other areas of KwaZulu-Natal and on expert opinion.

A1.3 Estuaries

A1.3.1 Introduction

Estuaries constitute the region where fresh water from terrestrial drainage meets and mixes with sea water (Allanson & Baird 1999). They are well known to be one of the most biologically productive ecosystems on Earth and are highly variable in terms of their geology, hydrology, salinity and sedimentation (Allanson & Baird 1999, Forbes & Demetriades 2008). Estuaries supply a wide range of provisioning, regulating and cultural ecosystem services.

There are a 16 estuaries found within the study area. From north to south these are the uTongati, uMdloti, oHlanga, uMngeni, Durban Bay, Isipingo, eziMbokodweni, aManzimtoti, Little aManzimtoti, iLovu, uMsimbazi, uMgababa, Ngane, uMkhomazi, uMahlongwane and iMahlongwa (Figure A1. 2). These range in size from only 9 ha to 910 ha, with a total estuarine area of about 2300 ha (Table A1. 3). The areas of the estuaries are taken from Forbes & Demetriades (2008) and represent the total estuarine area, including the area up to the flood lines and development set back lines.

Estuaries in South Africa fall into three biogeographical zones, with all of the KwaZulu-Natal estuaries falling within the Subtropical Zone. The Subtropical Zone extends from Mbashe Estuary to Maputo Bay. Upwelling seldom occurs along this stretch of coastline and estuarine water temperatures usually range from 14-28°C, with coastal sea water conditions often above 20°C due to the close proximity of the warm Agulhas Current (Whitfield 1998). The topography of the area is broadly similar to that immediately to the south and north of the municipal area in that it is hilly and rises steeply from the coast. This has resulted in the development of many of the smaller estuaries, although in cases such as the uMkhomazi, the catchment extends well beyond the western municipal boundaries all the way to the Drakensberg mountains (Forbes & Demetriades 2008).

South African estuaries can be classified into five major types, namely; estuarine bay, permanently open, river mouth, estuarine lake, and temporary open/closed (Whitfield 1992). The characteristics of each type of estuary are shown in Table A1. 3.

Table A1.3 Physical classification of estuaries (Source: based on Whitfield 1992)

Type	Typical size	Tidal Prism	Mixing Process	Average Salinity (PSU)
Estuarine Bay	Large	Large (>10 x 106m3)	Tidal	20-35
Permanently Open	Medium – Large	Moderate (1 - 10 x 106m3)	Tidal/Riverine	10->35
River Mouth	Small – Large	Small (<1 x 106m3)	Riverine	<10
Estuarine Lake	Large	Negligible (<0.1 x 106m3)	Wind	1->35
Temporarily open/closed	Small – Medium	Absent	Wind	1->35

Figure A1.2 The location of the 16 estuaries found within the EMA and their corresponding condition

A1.3.2 Estuaries of the EMA

All five of the estuarine types are represented within the KwaZulu-Natal Province but only four are found within the boundary of the EMA (Table A1. 4). The only type not represented in the EMA is that of large estuarine lakes, such as St Lucia. More than half of the estuaries found in the study area are highly degraded or in a poor state of health (Table A1. 4). The biggest threats to estuaries in the EMA include habitat loss, organic and chemical pollution from WWTW, informal settlements and industrial activities, unregulated sand mining, overexploitation, and upstream freshwater diversions or abstractions.

Table A1.4 Physical classification of estuaries in the eThekwini Municipal Area

Estuary	Classification	Total estuarine area (ha)	Health
uTongati	Temporarily open/closed	150.8	Highly degraded
uMdloti	Temporarily open/closed	99.5	Poor
oHlanga	Temporarily open/closed	86.3	Poor
uMngeni	Permanently Open	373.3	Highly degraded
Durban Bay	Estuarine Bay	2792.2	Highly degraded
Isipingo	Temporarily open/closed	598.8	Highly degraded
eziMbokodweni	Temporarily open/closed	57.1	Highly degraded
aManzimtoti	Temporarily open/closed	24.4	Highly degraded
Little aManzimtoti	Temporarily open/closed	22.1	Highly degraded
iLovu	Temporarily open/closed	62.0	Fair
uMsimbazi	Temporarily open/closed	69.6	Good
uMgababa	Temporarily open/closed	74.5	Good
Ngane	Temporarily open/closed	14.8	Fair
uMkhomazi	River Mouth	174.5	Fair
uMahlongwane	Temporarily open/closed	19.3	Good
iMahlongwa	Temporarily open/closed	76.7	Fair

Most of the estuaries in the EMA have been well studied and the main characteristics of each system are described in the Table A1. 5, based on information available in the literature. A comprehensive technical report of the estuaries of the eThekwini Municipality was produced in 2008 by Forbes & Demetriades and much of the below information comes from this study.

Table A1.5 Physical classification of estuaries in the eThekwini Municipal Area

Estuary	Water Quality	Vegetation	Fish	Birds	Major Impacts
uTongati	Poor WQ. High nutrient & poor oxygen levels. High levels of ammonia, polyaromatic hydrocarbons (PAHs) & certain pesticides. Algal blooms.	Proliferation of marginal & floating macrophytes. The northern bank dominated by coastal dune scrub & some swamp forest. Southern bank dominated by coastal forest and reeds.	Dominated by estuarine dependent species. Decline in fish species diversity & abundance.	Regional importance to the waterbird community. Dominated by common open-water birds & waders and species utilising estuaries as roosting areas.	Habitat loss. Poor water quality. Chemical contamination. Invasive alien plants. Unregulated sand mining.
uMdloti	WQ severely degraded as a result of ineffective waste water treatment and land use activities. Low salinity and oxygen levels. System is artificially eutrophic.	Highly modified vegetation. Cultivation of sugarcane in riparian zone. Narrow reed fringe remains. Some coastal forest on south bank. Proliferation of alien invasive species.	Largely dominated by estuarine & freshwater spp due to mouth closure for extended periods.	Locally diverse community of waterbirds. Low numbers of fish & invertebrate feeding birds.	Habitat loss.
oHlanga	Poor WQ. High nutrient & poor oxygen levels. Algal blooms.	Broad areas of reed swamp and coastal forest. Some secondary grassland and woody vegetation.	Low species richness and abundance. Numerous fish kills as a result of low oxygen in system.	Fairly diverse system, especially in terms of the piscivores.	Eutrophication. Freshwater diversions. Sewage (WWTW). Habitat Loss. Illegal gill net fishing
uMngeni	Poor WQ. Low oxygen levels in upper reaches. Nitrogen and Phosphorus levels fluctuate with open mouth conditions. High bacterial counts.	Beachwood mangroves important & relatively intact. Most of the other riparian vegetation lost through coastal development and canalisation in upper reaches.	Richest fish community in EMA but decline in conditions suggest impacts on fish diversity and abundance.	Highly abundant and diverse waterbird community but declines in certain species have been noted. Intertidal sandbanks attract numerous waders.	Sewage (WWTW). Chemical contamination. Habitat Loss. Freshwater diversions. Litter and debris. Eutrophication. Overexploitation (fishing and bait collecting)
Durban Bay	WQ severely degraded. Extremely high levels of faecal coliform bacteria in certain areas of the bay.	Mangroves. Diatoms found in the polluted areas. Seaweeds also occur certain areas.	Diverse and abundant fish community. Dominated by marine fish at mouth of bay and estuarine bottom feeders further in.	Waterbird community has declined significantly over the last few decades. Sandbanks do attract numerous waders.	Sewage. Chemical contamination. Habitat Loss. Freshwater diversions. Litter and debris. Eutrophication. Overexploitation (fishing and bait collecting) Introduced species.
Isipingo	Extremely poor water quality. Extremely high levels of faecal coliform bacteria, nitrogen and phosphorus.	Some mangroves on northern bank. Riparian vegetation reduced significantly. Water hyacinth	Highly impoverished fish community (lowest in the EMA).	Low abundance and diversity of bird assemblages.	Solid waste pollution. Sewage (WWTW) Habitat loss. Sedimentation. Freshwater diversions. Chemical and organic pollution.
eziMbokodweni	Extremely poor water quality. Organic pollution, high levels of bacteria, nitogen and phosphorus.	Canalisation of both banks of the eziMbokodweni has resulted in a complete loss of estuarine floodplain habitats. The riparian zone is confined to a narrow fragmented strip on the northern bank and is almost non-existent on the southern bank.	Carrying capacity of estuary small but relatively high abundance and diversity of fish.	Relatively low abundance and diversity but high numbers of piscivores.	Eutrophication. Habitat loss. Chemical and organic pollution. Increased flows from WWTW.
aManzimtoti	Extremely poor water quality as a result of a number of anthropogenic influences.	Riparian vegetation is very limited along the entire course of the system.	Relatively high abundance and diversity of fish.	Low abundance and diversity of bird assemblages.	Eutrophication. Habitat loss. Chemical and organic pollution. Weir at mouth. Alien species.
Little aManzimtoti	Poor water quality as a result of sewage effluent and other anthropogenic influences.	Riparian vegetation is very limited and alien invasive species have taken over.	Relatively high diversity for a small estuary, restricted to the mouth area.	Low abundance and diversity of bird assemblages. White-backed night heron recorded.	Eutrophication. Habitat loss. Organic pollution. Increased flows from WWTW.
iLovu	Nutrient concentrations low and water quality considered to be fair.	Riparian vegetation has been transformed and/or removed and has been invaded yby alien invasive species.	Diverse fish community, a result of favourable open mouth condition. Second most diverse in the EMA.	Strong presence of wading birds (intertidal sand banks). Low counts of piscivores.	Habitat loss. Sand mining.
uMsimbazi	Relatively good water quality with low bacteria levels. Some litter recorded in estuary.	Dense stand of P.australis in the middle of the estuary important.	Reasonably diverse fish assemblages	One of the most diverse bird communities in the EMA, with a large proportion of piscivores.	Canalization of floodplain. Habitat loss due to bridge construction.
uMgababa	Relatively good water quality with low bacteria levels.	The extensive sedge and reed beds along the course of the system represent a unique feature along the KwaZulu-Natal coastline.	Reasonably diverse fish assemblages	Reasonably diverse bird assemblages	Freshwater diversions (uMnini Dam)
Ngane	Relatively good water quality with low bacteria levels.	Reed bed at head of estuary and a few black mangroves are the only important botanical feature.	Low diversity and abundance as a result of the small size of the estuary.	Low diversity and abundance as a result of the small size of the estuary.	Floodplain encroachment. Habitat loss due to bridge construction.
uMkhomazi	WQ is fair with some organic pollution and eutrophication.	Very little natural riparian vegetation is left along the course of the system	Diverse fish community as a result of the open mouth of the system.	Relatively low diversity and numbers of waterbirds considered surprising given the size of the estuary and the presence of intertidal sandbanks.	Eutrophication. Organic pollution. Sand mining. Habitat loss.
uMahlongwane	Water quality is fair. High levels of nitrogen and phosphorus.	Dense stand of P.australis in the middle of the estuary important.	Relatively low diversity and numbers of fish	Relatively low diversity and numbers of waterbirds	Eutrophication. Habitat loss in the floodplain (sugarcane).
iMahlongwa	Water quality is fair. Bacteria levels higher in summer – thought to be from septic tank intrusion.	Large island of P.australis is prominent and and important feature in this system.	Relatively low diversity and numbers of fish	Relatively low diversity and numbers of waterbirds	Organic pollution. Eutrophication. Habitat loss in the floodplain (sugarcane).

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A1.4 Marine Environment

A1.4.1 Introduction

The coastline of KwaZulu-Natal extends for 640km and supports a greater number of species than any other stretch of South African coast (DAEARD 2010). The rich tropical biodiversity of the region is, in part, a result of the warm Agulhas Current that runs along the edge of the east coast of South Africa influencing species abundance, distribution and diversity, weather patterns and storm events (Palmer et al. 2011). The EMA marine environment covers a 98km stretch of this KwaZulu-Natal coastline and is characterised by offshore rocky reefs, rocky terraces and large sandy areas (DAEARD 2010). Beaches along the KwaZulu-Natal coast are generally unprotected, high-energy systems with fine to coarse grained sand and characteristically have coastal dune forests that flank the top of the shore (DAEARD 2010). However, within the EMA these dunes and coastal environments have been severely degraded or completely transformed as a result of extensive coastal development. Other threats include overexploitation and unregulated fishing, changes to the sediment and nutrient transport from estuaries to the sea and coastal pollution.

A1.4.2 Sandy beaches

The KwaZulu-Natal coast is typically dominated by sandy beaches which are dynamic and mobile ecosystems (Palmer et al. 2011) constantly changing as waves, wind and tides influence the shifting of sand both inshore and offshore. During rough conditions or storm events, large amounts of sand can be removed from the beaches by the sea and deposited offshore and during calmer periods, waves transport sand back onto the beach (Palmer et al. 2011). Durbans central beaches are sheltered by Durban Bay and are maintained through sand pumping operations. The sand on these central beaches is finer, the slope flatter and the waves more gentle when compared to other beaches of the region, making these beaches the most popular for tourism and recreation (eThekwini Municipality 2009).

A variety of organisms such as small crustaceans, burrowing worms, molecrabs and ghost crabs, clams and plough snails all inhabit sandy shores and are adapted to be able to deal with harsh conditions. Sandy shores are also important feeding grounds for birds, such as the sand plover. Beaches and dunes provide storm protection and are coastal buffers protecting the coastline from storms and absorbing and dissipating the energy produced by waves (eThekwini Municipality 2009). However, sandy beaches and associated dune systems are under constant pressure especially in the EMA where population growth and coastal development has lead to the excavation of beaches and dunes (eThekwini Municipality 2009). Climate change and associated pressures such as sea level rise and increased storm events also threaten these ecosystems. The loss of beaches and dune systems along this stretch of coastline threatens coastal property and infrastructure and will affect the overall functioning of the coastal ecosystem (eThekwini Municipality 2009).

A1.4.3 Rocky shores

Rocky shores are dynamic ecosystems and dominate sections of the KwaZulu-Natal coastline, especially the section of coast south of Durban Bay. Rocky shores can take the form of headlands, wide wave-cut platforms or rocky outcrops separated by sandy beaches (Palmer et al. 2011). Rocky shores are inhabited by a wide range of sessile and mobile organisms found at different vertical zones based tidal levels and inundation. Sessile organisms include barnacles, mussels, limpets, seaweed and redbait and mobile organisms include crabs, fish, sea urchins, sea cucumbers and sea stars (Palmer et al. 2011).

The invertebrate subsistence fishers collect a variety of rocky shore organisms which are a source of food secuirty. The main organisms harvested are mussels, redbait, oysters and octopus (DAEARD 2010). Rocky shore organisms are also harvested by recreational and subsistence line fishermen who use them for bait if they cannot afford sardines. A significant proportion of this harvesting is unregulated as a result overexploitation is a constant threat with easily accessible sections of rocky shore being completely devoid of many intertidal organisms.

A1.4.4 In-shore marine environment

The coastal waters off the KwaZulu-Natal coast are very diverse with approximately 2500 species of fish recorded, five species of turtle, 28 types of whales and dolphins, more than 46 seabird species and thousands of invertebrate species such as shellfish and octopus (Palmer et al. 2011). The diving and snorkelling sites associated with these coastal waters are popular tourist attractions and are also extremely popular with recreational fishermen (e.g. boat and land based linefishery and spear fishing).

The annual 'Sardine Run' which occurs in winter (usually between May and July) is a major tourism attraction for the region. Enormous shoals of sardines migrate from the Cape up the coast into the seas off KwaZulu-Natal attracting enormous numbers of other predatory gamefish such as elf, garrick, yellowtail, geelbek and dusky kob (Palmer et al. 2011). Sharks such as dusky and copper sharks, dolphins, seals, whales and seabirds are also attracted to the the vast food supply. When the sardines move close inshore licensed commercial fishermen attempt to catch the shoals using beach seine nets and recreational anglers attempt to catch gamefish and sharks (Palmer et al. 2011).

Although the east coast supports a wide range of fish and invertebrate species there are few commercial fisheries that actually operate. This is largely due to the fact that the KwaZulu-Natal coast is very nutrient poor when compared to the Atlantic coast which is dominated by upwelling events and subsequent high productivity. The continental shelf along the east coast is also very narrow, limiting the habitat available to support productive commercial fisheries (DAEARD 2010). Commercial fisheries operating on the east coast and within the EMA include commercial linefishing, prawn trawling, pelagic longlining, beach seine-netting, and oyster harvesting (DAEARD 2010, Everett 2014). Recreational and subsistence fisheries such as shore and boat-based linefishing are also important both ecologically and economically (DAEARD 2010).

APPENDIX 2: FLOOD MODELLING

Investigating the hydrologic ecosystem services provided by Durban's catchments (i.e. flow regulation) required comprehensive and complex hydraulic surface runoff models for all catchments that feed the full EMA. In order to achieve this, the US-EPA SWMM5 hydrology and hydraulics engine, interfaced by the PCSWMM software was selected. SWMM5 is an integrated, physically based model that was selected based on discussions with eThekwini Municipality's Catchment, Stormwater and Coastal Management (CSCM) department. CSCM has recently completed the migration of completed HEC-RAS hydrologic models of the EMA to SWMM5. The outputs from these models were used to estimate and map the value of hydrologic services. This appendix provides the methodology and model setup for the hydrological modelling used to determine the value of flow regulation in the EMA.

The aims of the hydrological modelling for ecosystem services valuation included:

- Estimating the influence of natural systems on flood hydrographs at selected points (e.g. above flood-prone areas/relevant infrastructure) for a range of return periods (RPs) by comparing outputs from the status quo (i.e. current baseline situation) with a hypothetical scenario where the infiltration and roughness of natural systems are modified to a "fully developed" situation.

Therefore the estimated effects of particular landscape units due to the modelled land use changes represent the principle outcome delivered by this hydrological modelling exercise.

A2.1 Model setup

The full eThekwini catchment system was modelled using the US-EPA SWMM5 hydrology and hydraulics engine, interfaced by the PCSWMM software. The model required a variety of baseline information, the details of which are outlined below. The calibration methodology adopted focused heavily on reducing the uncertainty during model set up.

A2.1.1 Baseline information

The modelling of landuse changes required a comprehensive complex hydraulic surface runoff model. The setup of the model for ecosystem service valuation required the integration of several GIS layers and post-processing for the hydraulic model input parameters. The following baseline information was used in developing the model:

- Various GIS datasets from the eThekwini Municipality, including: 0.5m Rasta .IMG files for surface elevation, 2m Contour, Landuse Zonal, Durban Metro Open Space System (D'MOSS), High resolution Aerial imagery;
- Shuttle Radar Topography Mission (SRTM) 30m resolution surface elevation data;
- Soil type classification maps;
- Geometric HecRAS hydraulic files for EMA rivers (where available);
- Stormwater networks (where available);
- Relevant point source data (e.g. WWTW);
- Design Rainfall Estimation (HydroRisk, http://ukzn-iis-02.ukzn.ac.za/unp/beeh/hydrorisk);
- eThekwini Design Rainfall (Smithers, 2002); and
- Water quality parameters and landuse change shapefiles.

A2.1.2 Software

The following specialised software was used for the model setup and calibration:

- QGIS;
- US-EPA SWMM5 interfaced by the PCSWMM GUI;
- HecRAS, Hec-Geo-RAS; and
- Anaconda – Spyder –Python 2.7 – Data Analysis/ Management.

A2.1.3 GIS land use layers

Available current GIS landuse files (e.g. zoning files, landcover and D'MOSS) were collated and reviewed. These files were concatenated into one consistent landuse polygon shapefile. Numerous errors and irregularities were found in the landuse zoning descriptions. Landuse files were merged from five different zones that make up the EMA and each of these files had their own set of landuse classifications. This meant that there was significant inconsistency in the landuse descriptions of the EM Hydrological Study. Further post-processing was performed to dissolve these descriptions into a common set of landuse conventions (see Figure A2. 1). In order to address any errors, the resulting shapefile was later 'groundtruthed' using aerial imagery for the whole of the EMA.

It is important to note that the original landuse descriptions from the D'MOSS landuse file (Figure A2.1) were maintained throughout the landuse description process and have been classified under "Nature and Conservation Areas". The D'MOSS classifications were further discretised to provide an indication of the hydraulic parameters required for the hydraulic model, i.e. grassland could be described as 'open_grass' or 'open_grass_soil' which indicates a higher soil erodibility.

The Southern African National Land Cover dataset (2013-14) was used for the catchments outside of the EMA. These data have been generated from multi-seasonal, 30 metre resolution Landsat 8 satellite imagery. The 72 different landuse descriptions were summarised into a more manageable list of landuse categories (Table A2.1). For example 'grass_medium' and 'grass_high' were labelled as 'grassland'.

LANDUSE CATEGORY	
1	Commercial
2	**Conservation & Nature Areas**
3	Education
4	Golf course
5	Harbour Industrial
6	Health Services
7	Industrial
8	Industrial Informal
9	Industrial Commercial
10	Informal Residential
11	Mineral Extraction
12	Open Space
13	Open Space / Mix
14	Public Facilities
15	Residential 1
16	Residential 1.5
17	Residential 2
18	Residential 3
19	Roads/Railways
20	Roads/Railways (excluding servitudes)
21	Roads/Railways with servitudes
22	Rural and Agricultural
23	Undeveloped Land
24	Waterbodies

D'MOSS layers	
1	Artificial waterbody
2	Estuary
3	Extractive
4	Field crops
5	Forest
6	Freshwater wetland
7	Grassland
8	Marine
9	Recreational
10	Rocky
11	Settlement
12	Thicket
13	Tree crops
14	Utility
15	Woodland

CN Subcategories
1. commercial_market_gardening
2. grass_maintained_gardens
3. dam_pond
4. forest_dense
5. forest_open_grassy
6. forest_open_grassy_soil
7. forest_sandy
8. grass_maintained
9. grass_maintained_with_bush
10. grass_unmaintained_soily
11. grass_unmaintained
12. grass_unmaintained_rocky
13. grass_soily
14. grass_soily_rocky
15. gravel_parking
16. impervious
17. large_scale_commercial
18. plantation
19. residential garden
20. rocky_soily

Figure A2.1 Landuse Categories and D'MOSS subcategories for all Conservation and Nature Areas within the EMA

Table A2.2 Landuse Categories used for the catchments outside of the EMA. These were then linked to the naming convention as shown in Figure 1.

LANDUSE CATGORIES			
1	Indigenous Forest	10	Cultivated subsistence crops
2	Thicket/dense bush	11	Settlements
3	Woodland/open bush	12	Wetlands
4	Low shrub land	13	Grasslands
5	Plantations/woodlots	14	Mines
6	Cultivated commercial annual: non-pivot	15	Waterbodies
7	Cultivated commercial annual: pivot	16	Bare ground
8	Cultivated commercial permanent orchards	17	Degraded
9	Cultivated commercial permanent vines		

A2.1.4 Subcatchment delineation

The study area was divided into subcatchments and the outlet points were identified (subcatchment runoff is routed to a single discharge point). Outlet points can be defined as nodes of the drainage system or they can be routed to other subcatchments.

The GIS subcatchment (watershed basins) data made available for this project were derived from EM flood studies and are in the order of 1km2 and larger. Although appropriate for flood studies, the information relevant to this scope of works required discretisation into smaller, more appropriate subcatchments, in the order of 0.2km2, within the EMA (Figure A2. 2). These new subcatchments were processed from high resolution, .IMG raster files (DEM files). The raster files were converted to .flt float files which can be used as a TIN (Triangulated Irregular Network). A spatial analysis tool was then used to process out the flow paths, watershed boundaries, and river centre lines.

For the region outside of the EMA, Shuttle Radar Topography Mission (SRTM – 30 x 30m cell size resolution) data were acquired and used to process the same special analysis tools to delineate watershed information. These two data sets were merged, as required for the scope of works. The SRTM data is not intended to provide detailed analysis results, but will allow for a qualitative assessment on a larger scale than just the EMA zone. The region outside of the EMA was discretised into approximately 0.5 to 1 km2 subcatchments with larger subcatchments closer to the Drakensberg Mountains. Both subcatchment files were merged into one file.

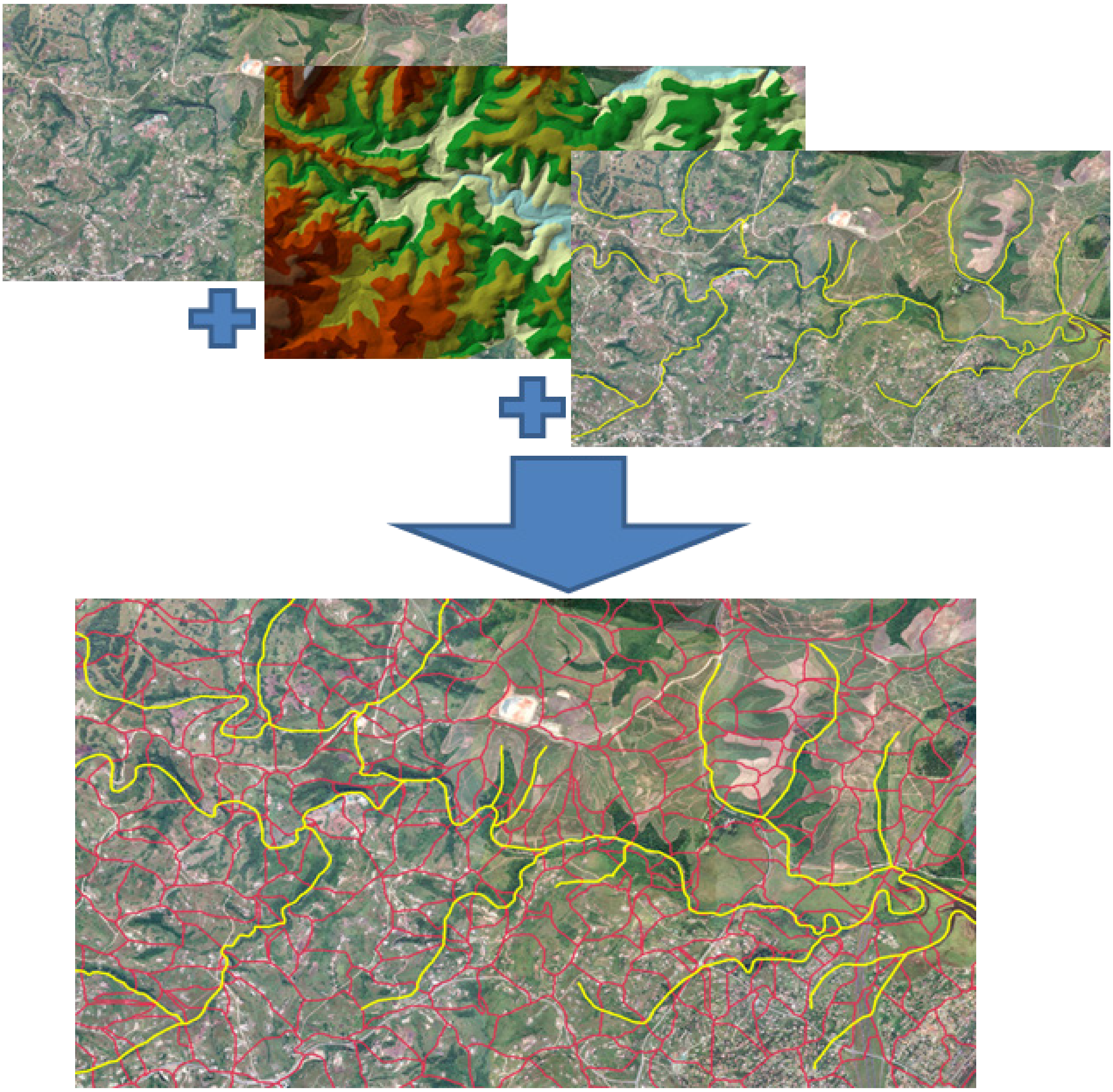


Figure A2.2 Information required to delineate subcatchments: topographical aerial survey, DEM and river centre lines based on river flow paths

A2.1.5 Flow lines

The EM flood models, based on geometric HecRAS files, were imported into the PCSWMM model (Figure A2. 3). The geometric file contains more information with regards to stormwater infrastructure (culverts, bridges etc.), however, it does not contain the stormwater network. These data sets only account for approximately 30% of the EMA and do not include the catchments beyond its boundaries. Flow paths simulated using a watershed delineation tool (WDT) were appended to the HecRAS files in order to represent the required study area.

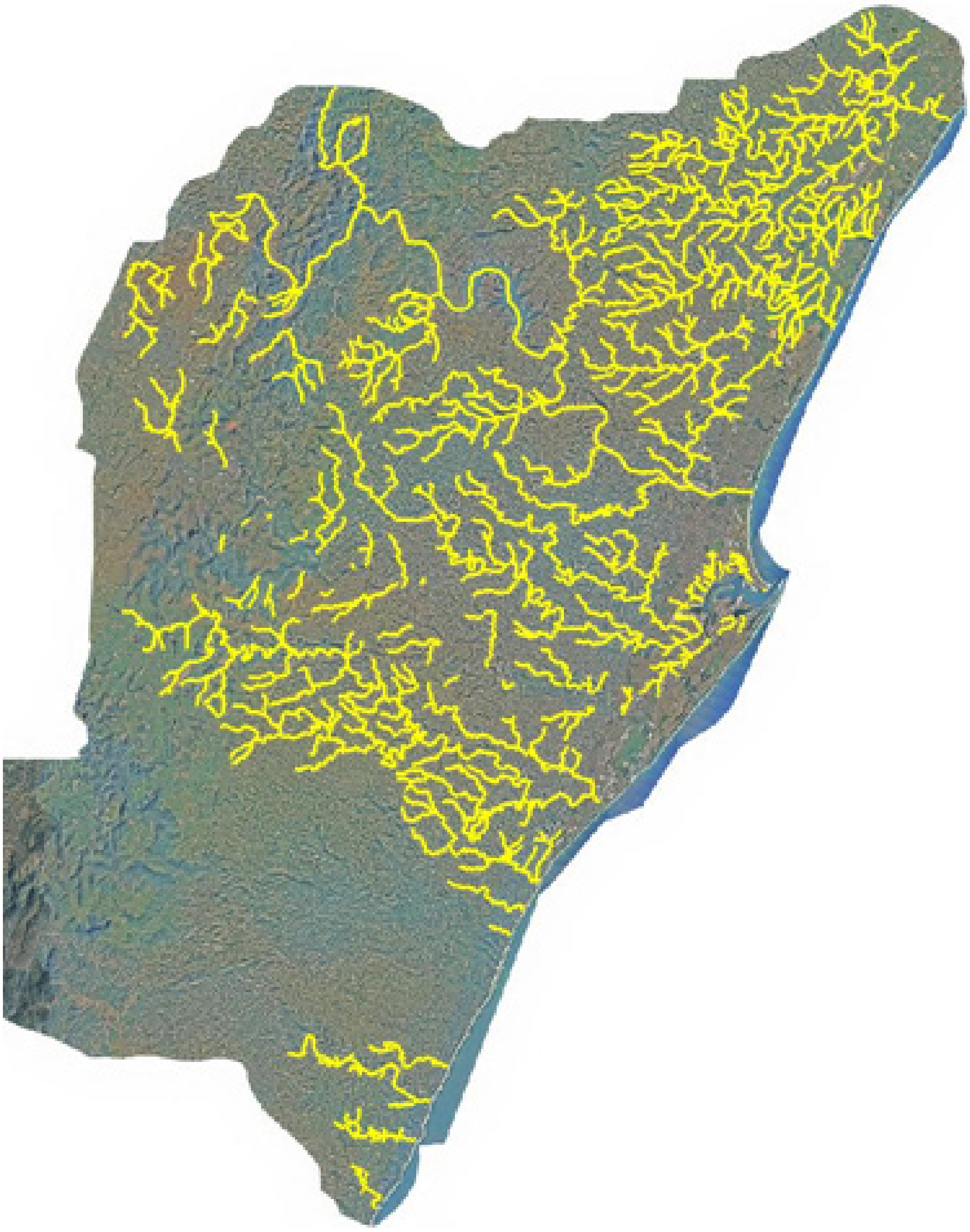


Figure A2.3 Illustration of HecRAS files merged and converted to SWMM5 layers for the study

There are a number of large dams in the eThekwini catchments, including Midmar Dam, Albert Falls Dam and Inanda Dam. Routing river flows through a dam is a fairly complex exercise which requires bathymetric data or hypsometric curves, time stamped/current water level data, knowledge of siltation rates and updates on whether the gates are open/closed, if there is overflow. In order to provide continuity through these dams and best represent the impacts of dams on flood flows, the model was split by routing all the flows entering the dam to an outfall (Figure A2. 4). Inflows were subsequently input downstream of the dams based on the analysis of data collected from the relevant water authorities.

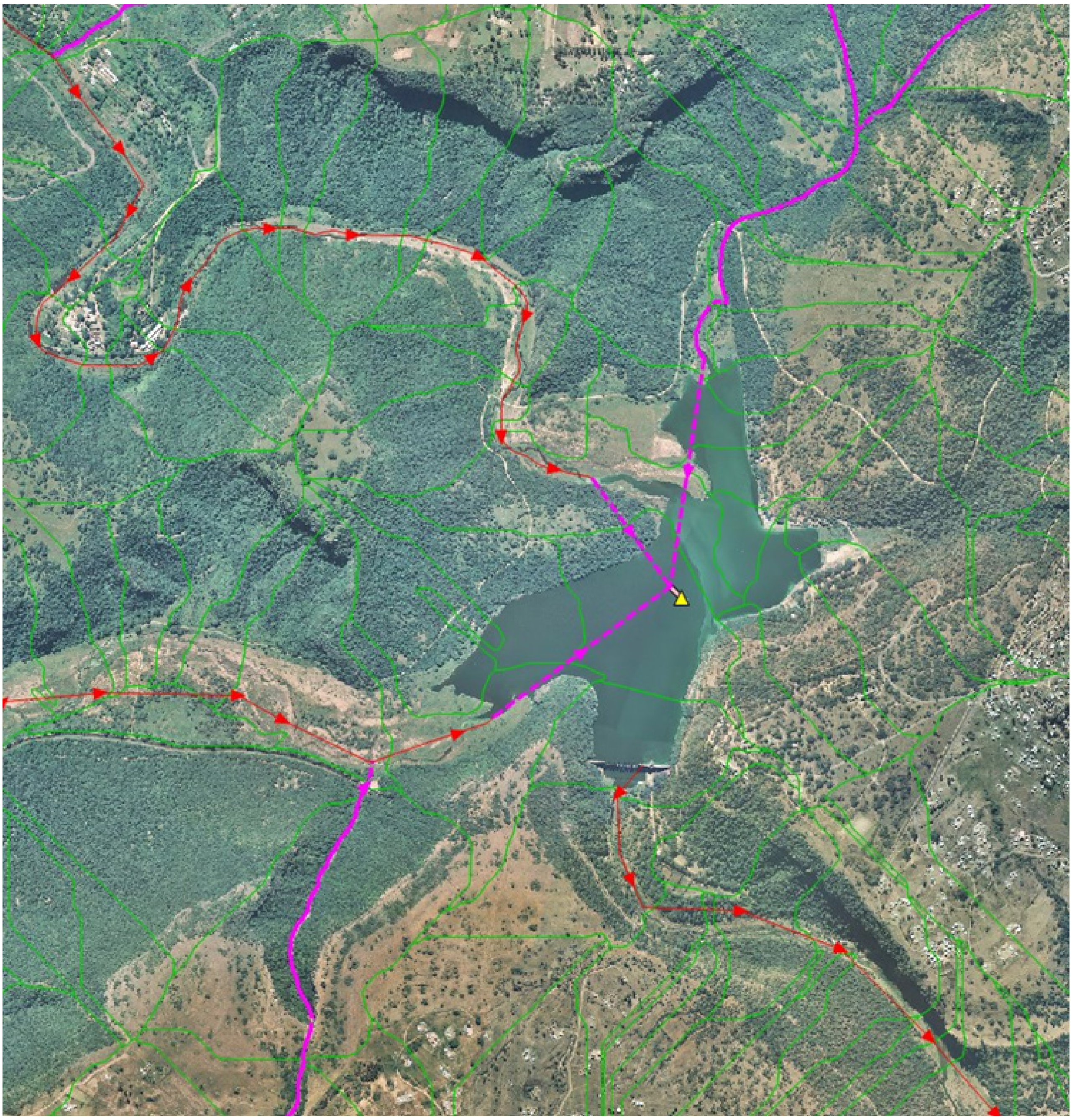


Figure A2.4 An example of flows entering and exiting a dam.

A2.1.6 Point sources

Average daily abstractions and return flows/discharges were added as point sources at the appropriate junctions. A list of the wastewater treatment works (WWTWs) located within the EMA is given in Table A2. 2. Note that the design capacity was used where the operating capacity was not given.

Table A2.3 WWTWs located within the study area.

WWTW Name	Latitude	Longitude	Design Capacity (Ml/d)	Operating capacity (Ml/d)	Subcatchment
Umkomaas	-30.20315	30.794653	1		U10M
Verulam	-29.64487	31.063288	13		U30B
Umhlanga	-29.69723	31.081528	6.8		U30B
Phoenix	-29.67962	31.037052	25		U30B
Umdloti	-29.6501	31.10941	3		U30B
Tongaat Central	-29.56028	31.137734	6	7.33	U30D
Gennazzano	-29.60671	31.156189	1.8		U30D
Fredville	-29.70166	30.644582	2		U20L
Northern Works	-29.79581	30.997692	70		U20M
New Germany	-29.80605	30.896683	7		U20M
Kwadabeka	-29.76397	30.929854			U20M
KwaMashu	-29.72957	31.008914	65		U20M
Magabeni	-30.16583	30.781316	1.3		U70E
Hammarsdale	-29.80025	30.66339	13		U60C
Cato Ridge			0.95		U60C
Mpumalanga	-29.80374	30.592571	6.4		U60C
KwaNdengezi	-29.86829	30.768762	2.4		U60D
Dassenhoek	-29.87836	30.793295	6		U60D
Southern	-29.95855	30.97295	230		U60D
Amanzimtoti	-30.00776	30.916413	27		U60E
Isipingo	-29.99021	30.906703	18.8	10.98	U60E
Umhlatuzana	-29.87713	30.884036	14.8		U60F
Umbilo	-29.84561	30.891653	23.2		U60F
Hillcrest	-29.7941	30.75635	1.2		U60F
Craigieburn			1.78		U80L
Central	-29.87683	31.060138	135		Bluff
Kingsburgh	-30.07451	30.856273	7.2		

A2.1.7 Stormwater network

A shapefile of the stormwater networks was provided by the eThekwini Municipality. The current available stormwater shapefile is incomplete and contains numerous errors and inconsistencies (see Figure A2. 5). Invert levels and pipe sizes are often missing and connections are incorrect and/or missing. For this reason, the stormwater network was only included in the U60F model. Available networks were amended where possible, i.e. a standard circular pipe size of 0.375m was allocated to pipes with missing geometry and tools were applied to either fill in missing invert levels (from the DEM) or to apply slopes within the network. Where necessary, main pipelines had to be added to these networks. The pipe profiles were later checked to ensure reasonable slope gradients and the continuity of flows.

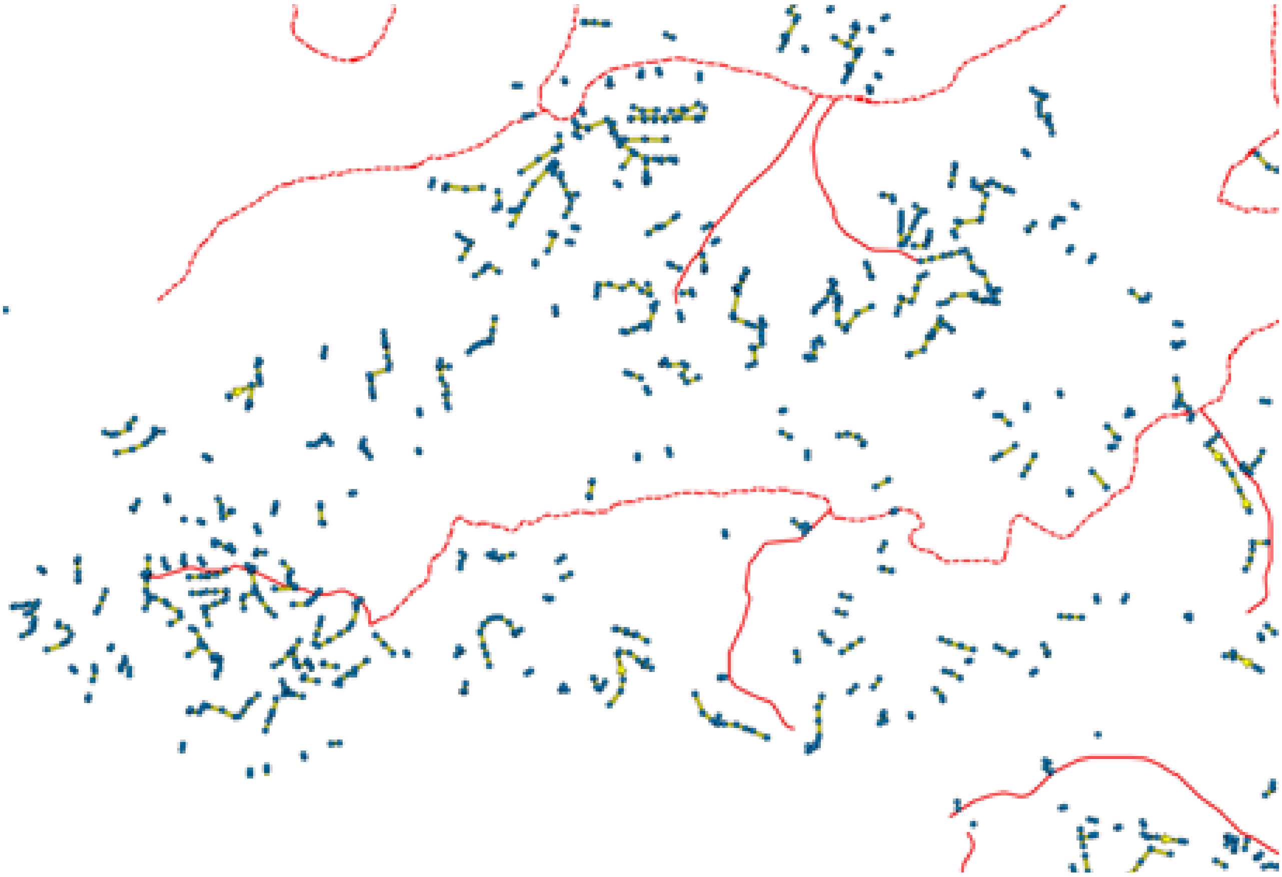


Figure A2.5 Current available stormwater shapefile (the red lines represent the flow paths, yellow lines are stormwater conduits and blue dots represent stormwater junctions).

The eThekwini Municipality is presently carrying out an SMS (Stormwater Management System) audit of all stormwater infrastructure. The audit entails a visual inspection and assessment of all stormwater infrastructure from which shapefiles of existing junctions, stormwater pipes and culverts are generated. Where available (see Figure A2. 6), these new shapefiles were imported into the model and connected to existing stormwater networks and flow paths. Continuity in these networks were checked and errors/connections were corrected where necessary. The original stormwater shapefile was merged with the new SMS shapefiles and both were connected to the HECRAS and WDT flow paths. Again profiles and connections were checked.

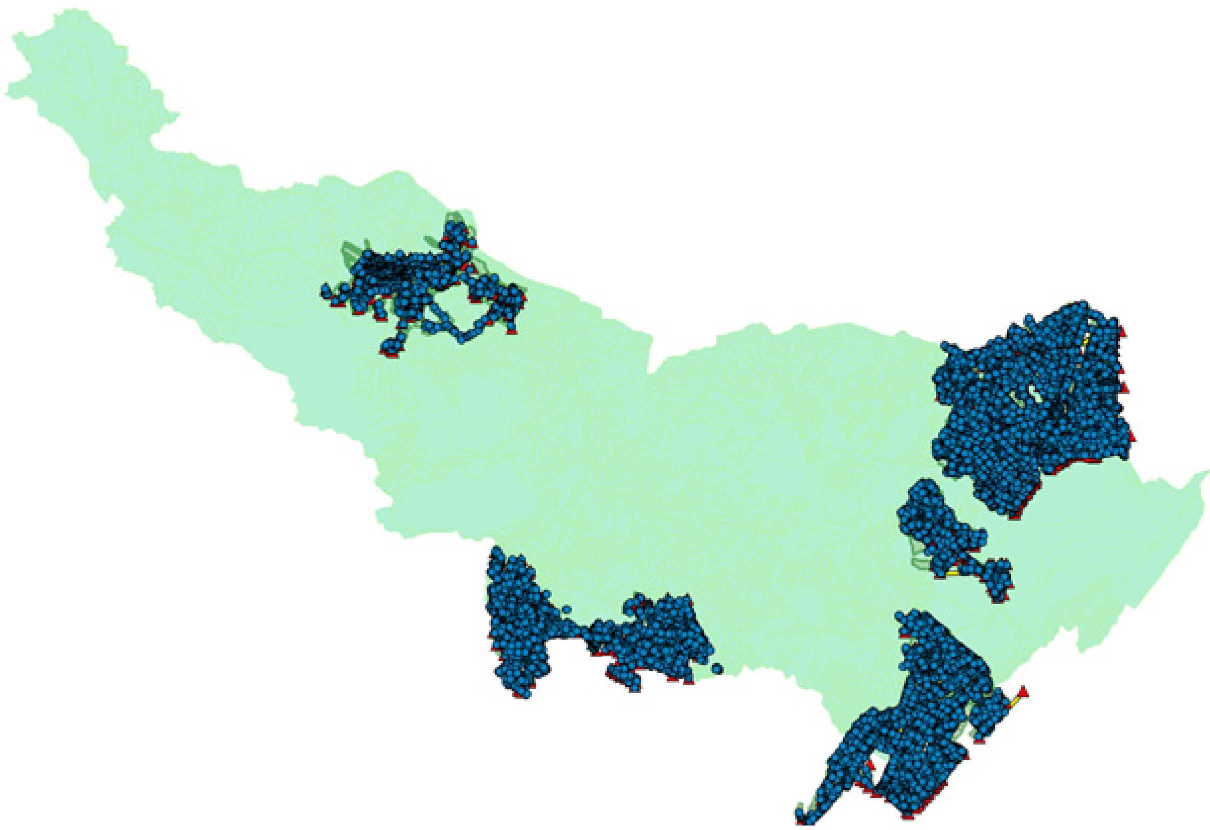


Figure A2.6 Newly available stormwater network shapefiles from the EM's SMS audit.

A2.2 Catchment characteristics

A number of input parameters are required for SWMM5. These include hydraulic parameters, soil infiltration properties, rainfall and water quality parameters.

A2.2.1 Hydraulic parameters

The determination of the catchment characteristics were estimated using a spatial analyst tool for zonal statics. Raster files were generated to represent the following information required for the hydraulic and hydrological models, with reference to each subcatchment. These were used to estimate the many runoff characteristics outlined in Table A2. 3.

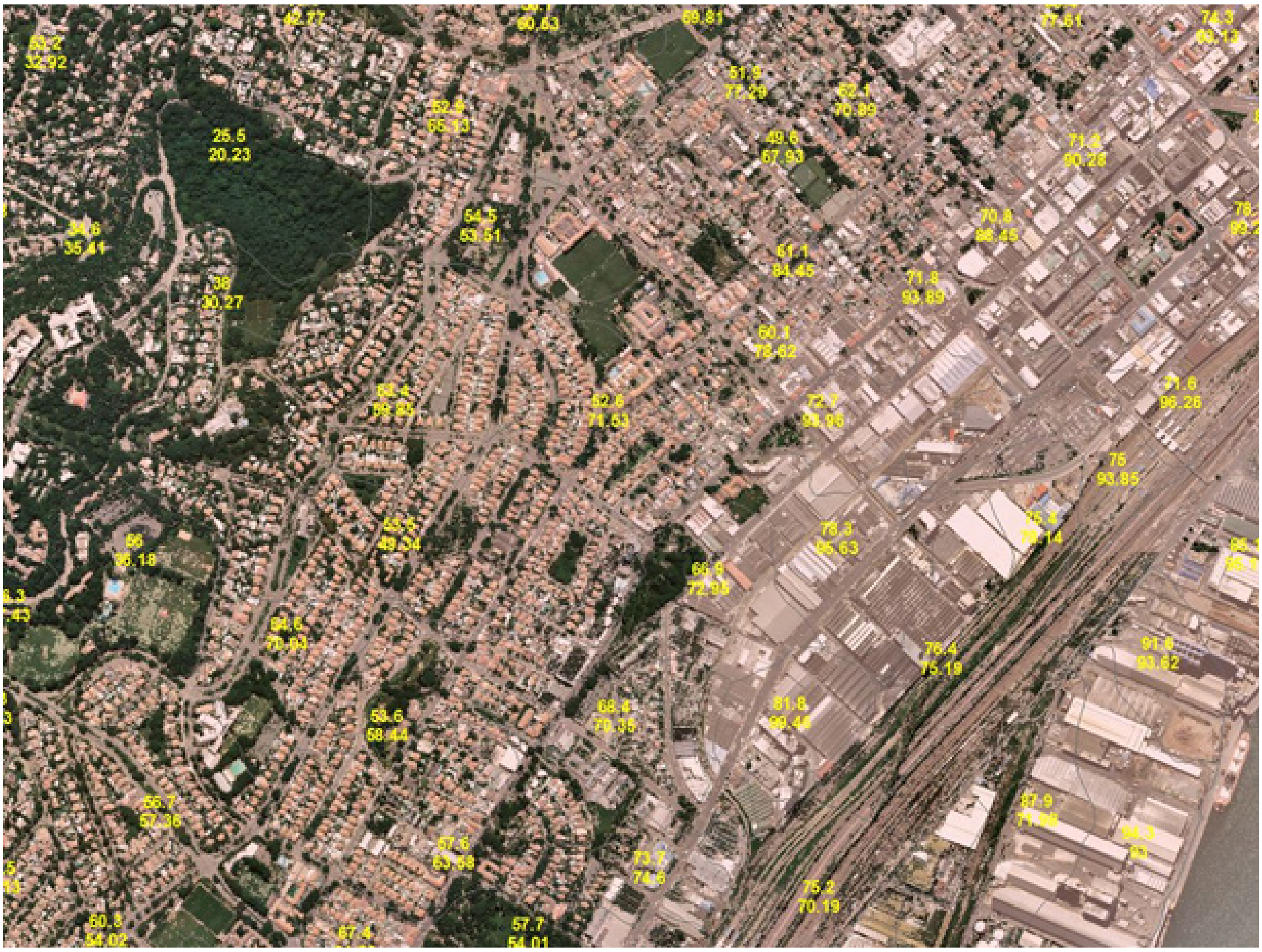
Table A2.4 Hydraulic input properties required for each subcatchment.

Hydraulic Parameter	Description	Source
Area (ha)	Area of subcatchment	GIS tool
Width (m)	Width of overland flow path	GIS tool
Flow Length (m)	Length of overland sheet flow	GIS tool
Slope (%)	Average slope along the pathway of overland flow to inlet locations.	GIS tool
Imperv. (%)	Percent impervious area	RGB colour extraction
N Imperv	Manning's roughness coefficient, N, for overland flow for impervious area.	Rossman, 2015 (Table 5)
N Perv	Manning's roughness coefficient, N, for overland flow for pervious area.	Rossman, 2015 (Table 5)
Dstore Imperv (mm)	Depth of depression storage on impervious areas	ASCE, 1992 (Table 4)
Dstore Perv (mm)	Depth of depression storage on pervious areas	ASCE, 1992 (Table 4)
Zero Imperv (%)	Percent of impervious area with no depression storage	SWMM default setting of 25% based on literature
Percent Routed (%)	Percent of runoff routed between sub-areas	Outfalls

Subcatchment areas were measured and the width of the subcatchment is defined as the physical width of the overland flow and in an idealised, rectangular catchment, the total width would be twice the length of the drainage channel (assuming both sides of the subcatchment are symmetrical).

The most significant input hydraulic parameter is the percentage of impervious area (Imperv. %). There are a number of methods that can be employed to estimate the percent imperviousness of a subcatchment. Ideally the percent imperviousness could be measured accurately from aerial photos or land use maps, however, this can be tedious for large study areas such as this one. Two approaches were investigated: 1) a percent impervious area was associated with each landuse category based on standard values for different landuses found in the literature and 2) RGB colour extraction tool was applied to differentiate between impervious and pervious areas based on aerial imagery (in the EMA) and Google Earth images (outside of the EMA). The EM has been working on the second approach, however we were not satisfied with the results and decided to use the first approach. Figure A2. 7 shows sections of two different areas of contrasting landuse i.e. residential and industrial. The top value represents the %Imperv using approach 1 and the bottom value represents the %Imperv using approach 2. The estimation using approach 2 was reasonable except where the colour spectrum was a mixture of green and brown, e.g. recently harvest sugarcane and rural sandy areas.

Figure A2.7 Percent impervious area for two different areas of contrasting landuse. The top value represents the %Imperv using approach 1 and the bottom value represents the %Imperv using approach 2.



The impervious and pervious N values were taken from literature. Estimates of Manning’s roughness coefficient (N values) for overland flow are taken from literature. A summary from three different sources are given in Table A2. 4.

Table A2.5 Estimates of Manning's roughness coefficient (N values) for overland flow. A summary from three different sources (Source: Rossman 2015)

Hydraulic Parameter	Description	Source	
Crawford and Linsley (1966)[a]	Smooth asphalt	0.01	
	Asphalt and concrete paving	0.014	
	Packed clay	0.03	
	Light turf	0.20	
	Dense turf	0.35	
	Dense shrubbery and forest litter	0.4	
Engman(1986)[b]	Concrete or asphalt	0.011	0.010-0.013
	Bare sand	0.010	0.01-0.016
	Graveled surface	0.02	0.012-0.03
	Bare clay-loa, (eroded)	0.02	0.012-0.033
	Range (natural)	0.13	0.01-0.32
	Bluegrass sod	0.45	0.39-0.63
	Short grass prairie	0.15	0.10-0.20
	Bermuda grass	0.41	0.30-00.48
Yen (2001)c	Smooth asphalt pavement	0.012	0.010-0.015
	Smooth impervious surface	0.013	0.011-0.015
	Tar and sand pavement	0.014	0.012-0.016
	Concrete pavement	0.017	0.014-0.020
	Rough impervious surface	0.019	0.015-0.023
	Smooth bare packed soil	0.021	0.017-0.025
	Moderate bare packed soil	0.030	0.025-0.035
	Rough bare packed soil	0.038	0.032-0.045
	Gravel soil	0.032	0.025-0.045
	Mowed poor grass	0.038	0.030-0.045
	Average grass, closely clipped sod	0.050	0.040-0.060
	Pasture	0.055	0.040-0.070
	Timberland	0.090	0.060-0.120
	Dense grass	0.090	0.060-0.120
	Shrubs and bushes	0.120	0.080-0.180
	Business land use	0.022	0.014-0.035
	Semi-business land use	0.035	0.022-0.050
	Industrial land use	0.035	0.020-0.050
	Dense residential land use	0.040	0.025-0.060
	Suburban residential land use	0.055	0.030-0.080
	Parks and lawns	0.075	0.040-0.120

[a] Obtained by calibration of Stanford Watershed Model
[b] Computed by Engman (1986) by kinematic wave and storage analysis of measured rainfall-runoff data
[c] Computed on basis of kinematic wave analysis

The depression storage is the volume that must be filled prior to the occurrence of runoff on both pervious and impervious areas. Values for depression storage were taken from the SWMM Manual (EPS 2015 after ASCE, 1992; Table A2. 5). In SWMM, depression storage may be treated as a calibration parameter, particularly to adjust runoff volumes. Therefore obtaining accurate values in the setup may be unnecessary as these value may change during calibration. Depression storage is most sensitive for small storms; as the depth increases it becomes a smaller component of the water budget (EPA, 2015).

Table A2.1 Values used for the depression storage based on landuse (ASCE, 1992)

WWTW Name	Latitude
Umkomaas	-30.20315
Verulam	-29.64487
Umhlanga	-29.69723
Phoenix	-29.67962

A2.2.2 Soil Infiltration

The largest proportion of rainfall losses over pervious areas generally occur due to soil infiltration. Theoretically the Richards equation is the most representative, however its highly nonlinear partial differential equations make is unsuitable for continuous long-term simulations. Simpler algebraic infiltration models have been developed that represent the dependence of infiltration capacity on soil characteristics and the present soil capacity during a storm event. There are five options that can be used in SWMM, namely Horton's method, the modified Horton method, the Green-Ampt method, the modified Green-Ampt method and the Curve Number method. With all of these models, the parameters depend on the type and condition of the soil of interest.

It is worth noting that the Flood Line Delineation studies for EM use the Soil Curve Number (SCN) to represent the runoff co-efficient for catchment routing. Although suitable for flood studies (as a conservative approach), this investigation will use the Green-Ampt method. This methods provides a soil memory as opposed to a broad brush coefficient approach.

For the Green-Ampt infiltration method, the model requires three soil parameters that the user must specify for each of the subcatchments:

1. Capillary suction head, Ψs (mm);
2. Saturated hydraulic conductivity, Ks (mm/hr); and
3. The maximum available moisture deficit, θdmax (volume of dry voids per volume of soil).

These parameters were taken from the SWMM Manual (Table A2. 6). Figure A2. 8 is a map of the green-ampt parameters for the study area that has recently been developed and applied during a current Water Research Commission (WRC) study by Pegram and Sinclair at the University of Kaw-Zulu Natal (UKwaZulu-Natal). These parameters will be used and the results compared with those using the parameters given in Table A2.6.

Table A2.6 Values used for the depression storage based on landuse (ASCE, 1992)

Soil Texture Class	Suction Head (mm)	Hydraulic Conductivity (mm/hr)	Initial Deficit (fraction)	Porosity (fraction)	Field Capacity (fraction)	Wilting Point (fraction)
Sand	49.02	120.34	0.413	0.437	0.062	0.024
Loamy Sand	60.96	29.97	0.39	0.437	0.105	0.047
Sandy Loam	109.98	10.92	0.368	0.453	0.19	0.085
Loam	88.9	3.3	0.347	0.463	0.232	0.116
Silt Loam	169.93	6.6	0.366	0.501	0.284	0.135
Sandy Clay Loam	219.96	1.52	0.262	0.398	0.244	0.136
Clay Loam	210.06	1.02	0.277	0.464	0.31	0.187
Silty Clay Loam	270	1.02	0.261	0.471	0.342	0.21
Sandy Clay	240.03	0.51	0.209	0.43	0.321	0.221
Silty Clay	290.07	0.51	0.228	0.479	0.371	0.251
Clay	320.04	0.25	0.21	0.475	0.378	0.265

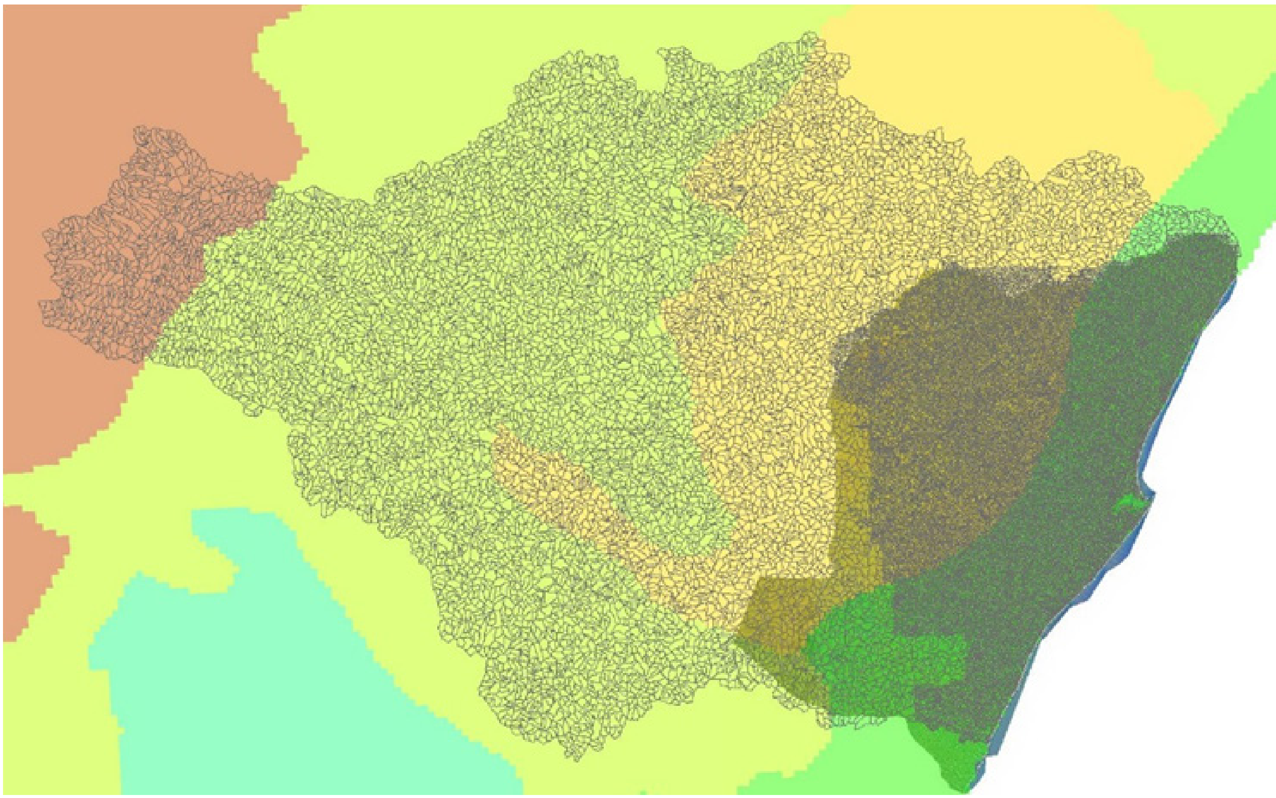


Figure A2.8 Map of Green-Ampt Parameters developed by UKwaZulu-Natal (Source: Sinclair 2015)

A2.2.3 Water quality parameters

The water quality parameters chosen for this study are nutrients (nitrogen, phosphorous) and total suspended solids (TSS). The landuses that generate these pollutants were defined and the pollutant buildup, pollutant washoff and street cleaning parameters were assigned to each landuse. The pollutant removal functions for nodes within the drainage system that contain storage/ treatment facilities were also defined. The input parameters for each pollutant are as follows:

- the pollutant name;
- the concentration units (i.e. mg/L, µg/L, counts/l);
- oncentration in rainfall;
- concentration in groundwater;
- concentration in direct infiltration/inflow; and
- first-order decay coefficient.

The landuses that generate these pollutants were defined and the pollutant buildup, pollutant washoff and street cleaning parameters were assigned to each landuse. Note that no data was available to estimate the pollutant buildup and street cleaning parameters and therefore these features were not considered. The pollutant washoff from a given land use occurs during periods of wet weather and can be characterized in SWMM5 by either using an exponential or rating curve relationship. The Event Mean Concentration is a case of Rating Curve Washoff where the exponent is 1.0 and the coefficient represents the washoff pollutant concentration in mg/L. In each case buildup is continuously depleted as washoff proceeds, and washoff ceases when there is no more buildup available. The EMCs were derived from literature (Table A2. 7). These data were applied to the different landuse categories across the study area. The data below can be applied in determining the water quality volume to be catered for in stormwater management devices (e.g. SUDS).

Table A2.7 Event Mean Concentration (EMC) data for different landuse types

Landuse Description	TSS (mg/l)	BOD (mg/l)	TIN (mg/l)	P (mg/l)
Settlement - urban	100	15	3.41	0.79
Commercial / Retail / Institutional	166	9	2.1	0.37
Industrial / Road & Rail	166	9	2.1	0.37
Extractive / Utility	166	9	2.1	0.37
Farming / plantations & woodlots	201	4	1.56	0.36
Recreational open space	201	4	1.56	0.36
Settlement - rural	201	4	1.56	0.36
Natural vegetation (D'MOSS)	70	6	1.51	0.12
Settlement - informal	497		22	6.7

A2.3 Storm design events

Standard techniques for flood estimation generally include the analysis of observed peak discharges and event modelling using rainfall-runoff techniques, however observed streamflow data are often not available in South Africa. The most common technique for many engineering and conservation design decisions is therefore to use rainfall event-based methods. Smithers and Schulze (2000) compiled tables of design rainfall depths at selected rainfall stations for different durations based on frequency analysis of the annual maximum precipitation for a given duration from historical rainfall data. This data is listed based on a latitude and longitude grid for a variety of recurrence intervals from 2 to 1000 years for storm durations from 5 minutes to several days. The duration of design rainfall may range from five minutes for small urban catchments (with a rapid hydrological response) to a number of days for large regional flood studies.

The design rainfall depth used in design flood estimation should be based on the critical storm duration or time of concentration (TC) of a catchment. The TC is defined as the time required for rainfall based runoff, with a spatially and temporally uniform distribution, to contribute to the peak discharge at the outlet of the catchment outlet.

The eThekwini Municipality design rainfall spreadsheet based on Smithers (2002) analysis of the region was assigned to each subcatchment using an area-weighting tool. One method is to assign a rainfall distribution to the time of estimated concentration (Tc) for each subcatchment. The SCS Type II distribution is the most relevant in general, and the total rainfall for a given Tc will be used to calculate the intensity for each RP (Figure A2.9).

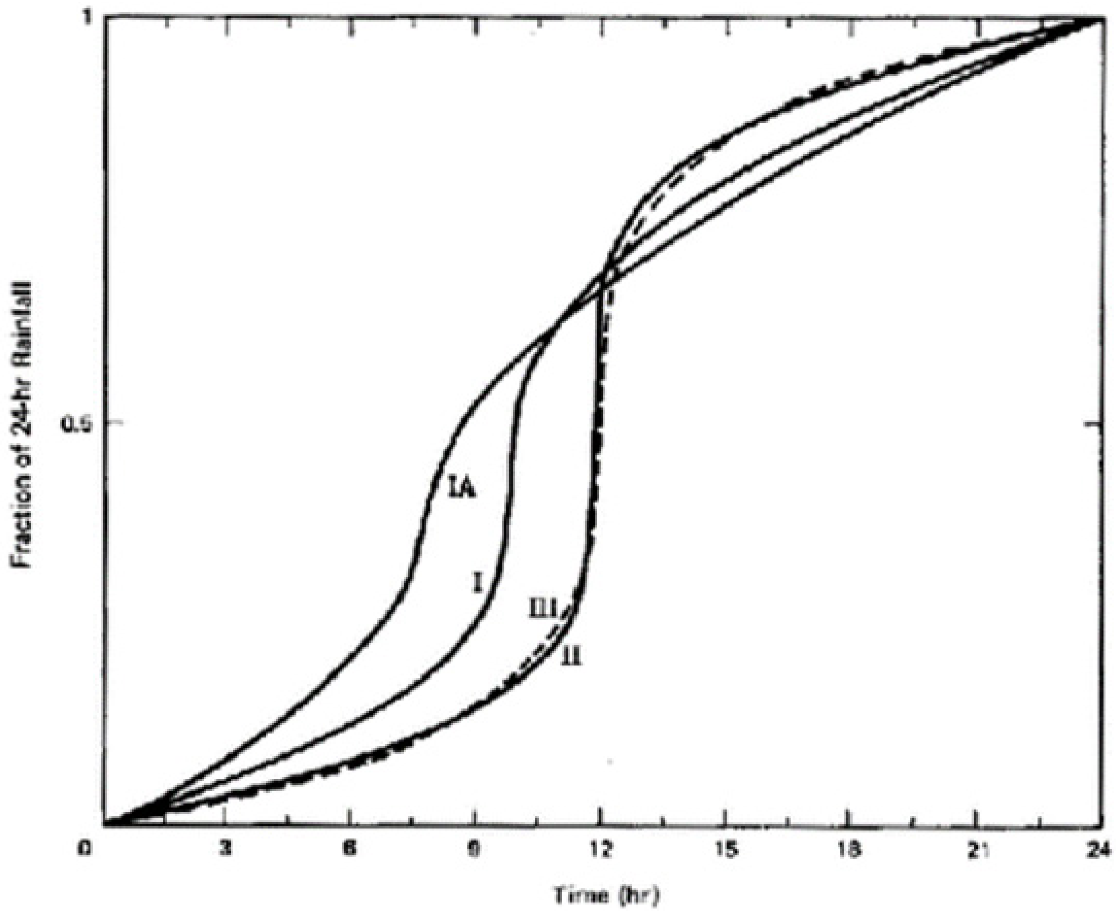


Figure A2.9 SCS 24-hour rainfall distributions (not to scale) (Source: SCS 1984)

The Design Rainfall for the areas outside of the EMA were taken from the tables derived by Smithers and Schulze (2002) for a 5, 10, 20 and 50-year return period (Table A2. 8). The RPs relevant to this study have been summarized below.

Table A2.8 Design rainfall for area outside of the EMA (Smithers and Schulze, 2002).

Station ID	Station name	MAP	Altitude	Years	Duration (days)	Return Period (years)					
						2	5	10	20	50	100
0239482W	CEDARA	876	1134	40	1	56	78	95	114	142	167
0238806W	Emerald Dale	902	1209	40	1	61	82	98	114	137	155

A2.4 Final Model

The final SWMM model of the full EMA comprised about 30 000 subcatchments. The eThekwini catchment system was divided into 3 separate models, representing the northern, central and southern catchments in order to reduce simulation running times (Figure A2. 10, Figure A2. 11, Figure A2. 12, and Figure A2. 13).

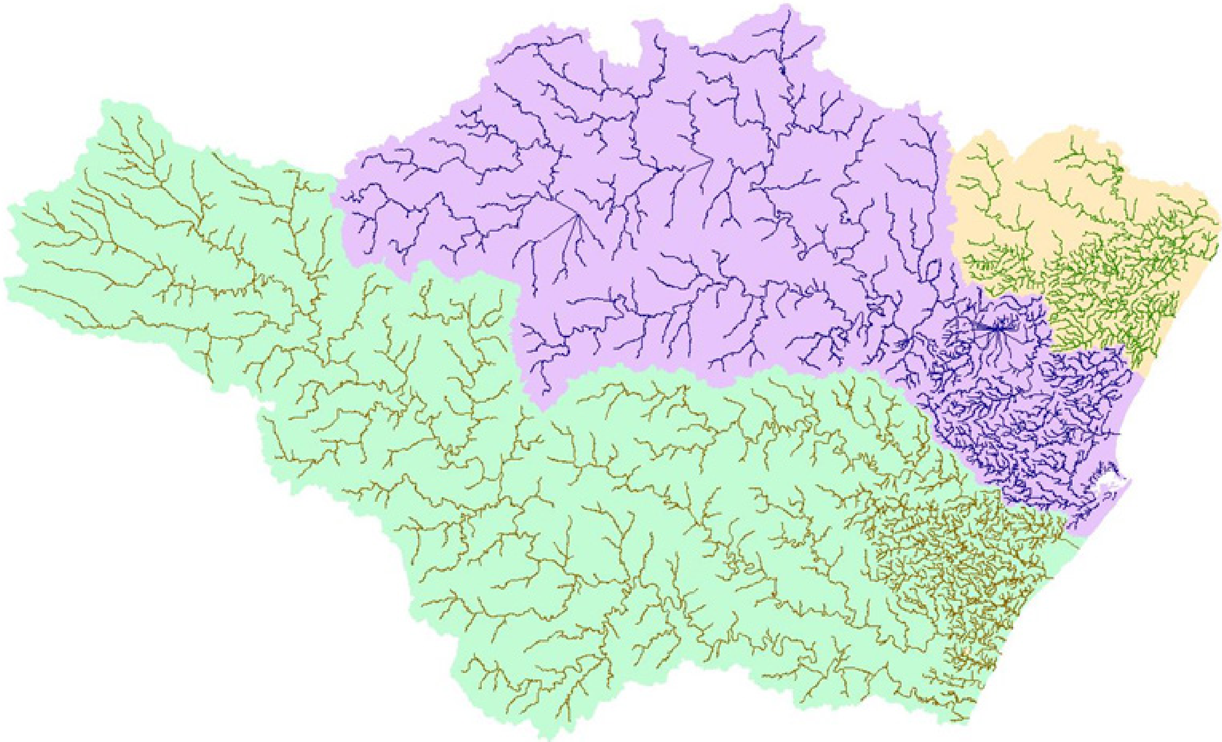


Figure A2.10 The full eThekwini catchments showing flow paths

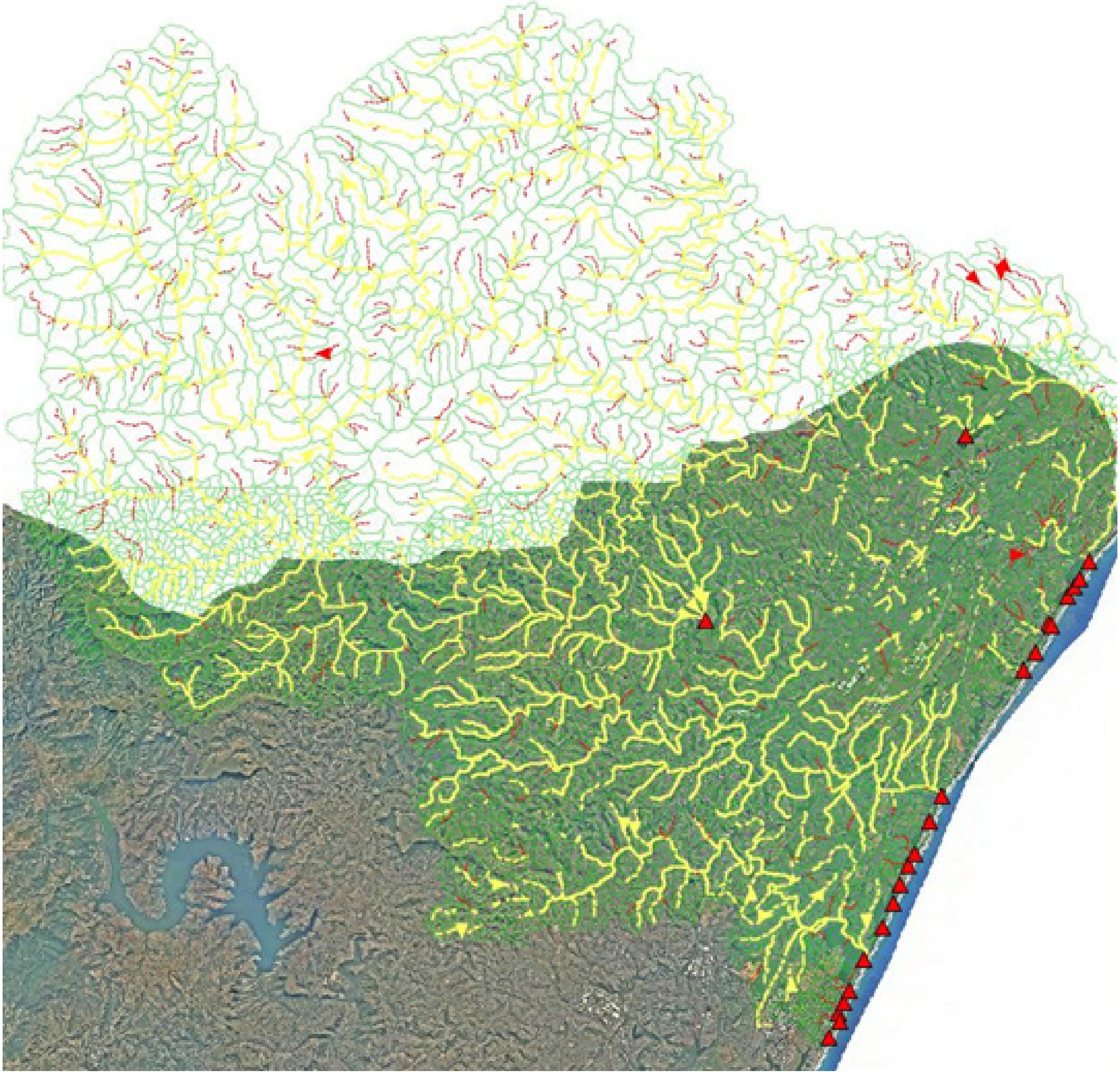


Figure A2.11 Snapshot of the SWMM model of the Northern EMA catchments.

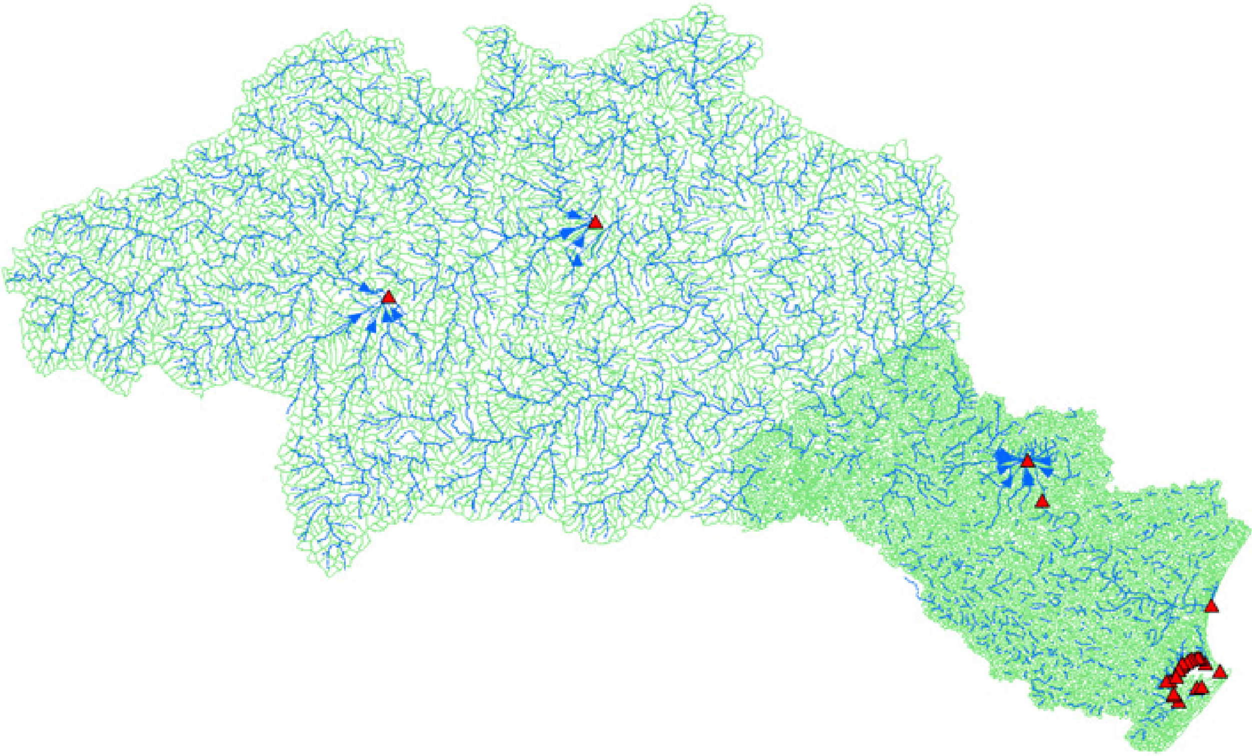


Figure A2.12 Snapshot of SWMM model of the Central EMA catchments.

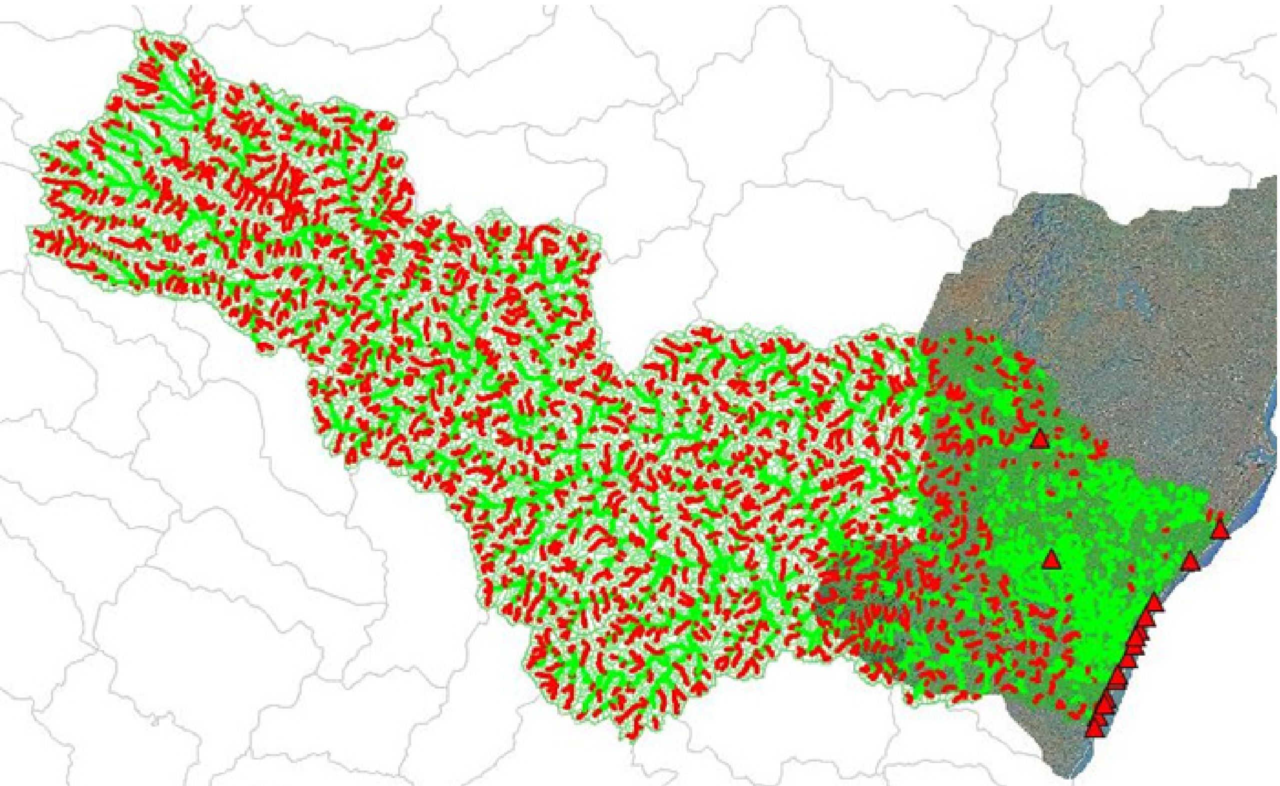


Figure A2.13 Snapshot of the SWMM model of the Southern EMA catchments.

A2.5 Model calibration and validation

Real-time data was used for model calibration and validation. This was done using the data and methods outlined below. Flows and water quality within the EMA are relatively well monitored, however there are limitations with using these data for calibration purposes. These limitations are discussed below.

A2.5.1 Rainfall Selection and Application

Phase 1 of the calibration and validation was focused on the hydraulic flows and volumes. Real-time rainfall data available from the EM and the South African Weather Services (SAWS) was used in conjunction with measured river water levels at several locations. For the region outside of the EM, real-time rainfall data (5 minute intervals) were obtained from the SAWS for a number of rainfall stations (Table A2. 9). Real-time rainfall data for the EMA was obtained from the EM database (Figure A2.14).

Table A2.9 Real-time rainfall data was obtained for the following stations outside of the EMA (Source: SAWS)

	Rainfall Station ID	Latitude	Longitude
1	Emerald Dale	-29.940300°	29.959700°
2	Mooi River	-29.218000°	30.002500°
3	Cedara	-29.541700°	30.265000°
4	Shaleburn	-29.352500°	29.786900°

Figure A2.14 Locations of the available rain gauge stations in the EMA (Source: eThekwini Municipality)

The Thiessen polygon method was applied to the rainfall stations and each rain gauge was assigned to a certain area (Figure A2. 15).

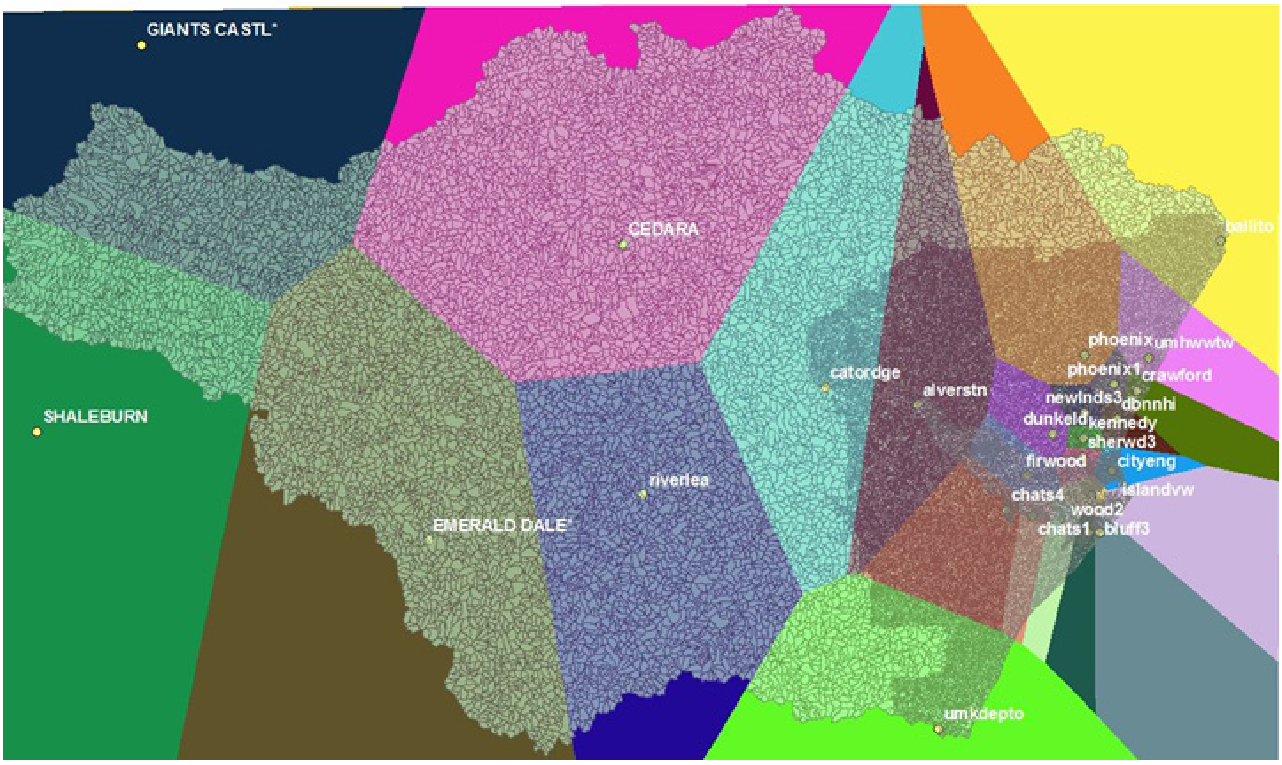


Figure A2.15 Thiessen polygons determined for the full EMA catchments.

A2.5.2 Available measured data

The efficacy of calibration depends entirely on the availability of measured data. Flow and/or water level data are most useful for the calibration of the hydraulics. Several real time rainfall data sets were applied in order to calibrate the models. Calibration points were chosen on rivers without dams and where flow data were available. It was not possible to address every river in such a large system. The calibration parameters were applied to similar landuse zones in general, and as such were used in all of EM during the process.

The EM recently deployed a number of water sensors in the U60F catchment (in the Umhlatuzana and Umbilo Rivers) over two separate time periods. However, unusually heavy rainfall was experienced during both periods (including an almost 100-year flood) and most of the sensors were washed away. Two sensors were retrieved - one in the Umbilo River and the one in the Umhlatuzana River. This data provides an indication of baseflows which help to validate the accuracy of abstractions and return flows in these rivers.

The eThekwini Municipality's Water and Sanitation Department measure river, outfall, stormwater and beach water quality at numerous monitoring stations within the EMA. Of these points, many do not measure nutrient concentrations. Table A2. 10 provides a list of the available monitoring stations and measured data for the EMA and Table A2. 11 provides a list of the sampling points in the EMA that measure Ammonia (free), Nitrates and Nitrites (DIN), orthophosphates (P) and turbidity.

Table A2.10 DAvailable hydrology monitoring stations within the full EMA catchments from the Department of Water and Sanitation.

Gauge number	Gauge Name/Location	Catchment Area (km²)	Latitude	Longitude	Available data
U1H005	Mkomazi River @ Lot 93 1821	1744	29.74369	29.90494	1960-08-14 2016-01-19
U1H009	Mkomazi River	4328	30.13561	30.67372	2004-05-06 2016-05-12
U2H005	Mgeni River @ Table Mountain	2519	29.57603	30.60258	1950-11-01 2016-01-29
U2H006	Karkloof River @ Shafton	339	29.38175	30.27775	1954-01-04 2016-05-30
U2H007	Lions River (Mpofana River) @Weltevreden	358	29.44258	30.14853	1954-07-16 2016-05-30
U2H011	Msunduze River @ Henley Dam	176	29.64708	30.25975	1957-12-24 2016-01-26
U2H012	Sterk River @ Groothoek	438	29.42306	30.48828	1960-08-11 2016-01-26
U2H013	Mgeni River @ Petrus Stroom	299	29.51261	30.09442	1960-08-10 2016-05-30
U2H022	Msunduze River @ Inanda Loc.	881	29.66086	30.63617	1983-09-07 2016-01-27
U2H041	Msunduze River @ Hamstead Park	534	29.60772	30.45025	1996-01-31 2016-02-09
U2H055	Mgeni River @ Inanda Loc.	2624	29.64244	30.68861	1989-10-26 2016-01-14
U2H057	Slang Spruit @ Pietermaritzburg	48	29.63072	30.35322	1995-06-02 2016-02-09
U2H058	Msunduze River @ Masons Mill	327	29.64144	30.36544	1995-04-25 2016-02-09
U2H061	Mpofana River		29.39162	30.06297	2013-02-26 2016-02-23
U3H001	Tongati River @ Riet Kuil	236	29.53368	31.08922	1966-10-07 2016-02-25
U4H010	Kleinspruit	16	29.04139	30.56306	1999-06-29 2016-02-04
U6H002	Mlazi River @ Nooitgedacht	105	29.749	30.317	1981-07-13 2016-05-23
U6H003	Mlazi River @ Umlaas	417	29.80395	30.51587	1981-11-13 2016-04-15
U7H001	Zwateni River @ Highlands	16	29.84733	30.23531	1949-07-09 2016-05-23
U7H007	Lovu River @ Beaulieu Estate	114	29.86244	30.24417	1964-10-13 2016-05-23
U7H012	Nungwana River @ Umbumbulu	51	30.00597	30.71214	1997-08-20 2016-02-11
U8H003	Mpambanyoni River @ Umbeli Belli	378.8	30.27403	30.69603	1987-05-27 2016-01-20

Table A2.11 Water quality monitoring stations within the EMA.

Sampling station	River	Sampling station	River
R_Zana_10 R_Zana_28 R_Zana_29 R_Zana_34 R_Zana_35	Umhlatuzana	R-MLAAS_39 R-MLAAS_75 R-MLAAS_76 R-NDENGEZI R-DASSENHOEK R-STERK_03 R-STERK_05	uMlaas River
R_Umbilo_04 R_Umbilo_13 R_Umbilo_27	Umbilo	R-MKOMAZI_03 R-MKOMAZI_S	uMkomazi River
R-BOKODWENI_02 R-BOKODWENI_03 R-HLONGWANA_01 R-HLONGWANA_02	South Durban	R_NGANE_02 R_NGANE_03	Ngane River
R-ISPINGO_00 R-ISPINGO_01 R-ISPINGO_03 R-ISPINGO_04 R-ISPINGO_05	Isipingo River	R-OHLANGA_08 R-OHLANGA_07 R-OHLANGA_05 R-OHLANGA_02 R-OHLANGA_01	oHlanga River
R-LTOTI_00 R-LTOTI_02 R-LTOTI_05	Little aManzimtoti	R_THONGATI_02 R_THONGATI_03 R_THONGATI_04	uThongati River
R-MDLOTI_01 R-MDLOTI_02 R-MDLOTI_03 R-MDLOTI_04 R-MDLOTI_05	uMdloti River	R-ILLOVU_02	iLovu River
R-MGENI_08 R-MGENI_71 R-MGENI_75 R-MGENI_80 R-MGENI_71 R-ALLER_01 R-GANE_04 R-GANE_18 R-NKUTU_01	uMngeni River		

A2.5.3 Calibration of flows and water levels

The models were calibrated using available measured flow and water quality data. Note that in some cases gauging stations did not provide adequate data for calibration purposes, for example there is no measured flow data for the Umbilo and Umhlatuzana Rivers. Therefore, emphasis was placed on setting up the model as accurately as possible. Simulated peak flows for the rivers were compared with those estimated in other studies conducted in the EMA by Jezewski (1984) and Mkwananzi & Pegram (2004). Although the calibration period allowed for this study was very time constrained, we feel the results of the model are within an acceptable range. The results certainly highlight the changes between between different river systems with regards to subcatchment area size and shape. For the purposes of this study there is reasonable certainty in the model outputs.

The full eThekwini catchment system was divided into 3 separate models, representing the northern, central and southern catchments in order to reduce simulation running times. Models were calibrated separately. Measured flows and water depths were compared with simulated flows and water depths on the uMsunduze (uMgeni) River. Simulated water levels were lower than measured water levels. Return flows from the wastewater treatment works were added as a constant 'baseflow'. There appears to have been an irregularity in the measured data with the large rapid increase in flow and water level, this was neglected (Figure A2. 16).

There is reasonable agreement between the simulated water depths and the measured water depth at the DWA gauging station on the Nungwana River at Umbumbulu (Figure A2. 17). The simulated peak flows were, however, predicting much higher flows than those measured at the gauging stations. This indicates that the actual losses were higher than in the modelled flows (the volume of the simulated flows is greater than the volume of measured flows as shown in (Figure A2. 18). In addition, the simulated flows respond much quicker to rainfall. In order to smooth out the simulated peak flows and reduce the simulated volumes, the flow paths were increased to include more tributaries, thereby increasing the time of concentration (see Figure A2. 19). As you can see in Figure x the weir is located downstream of a small dam which may also be smoothing out measured peak flows.

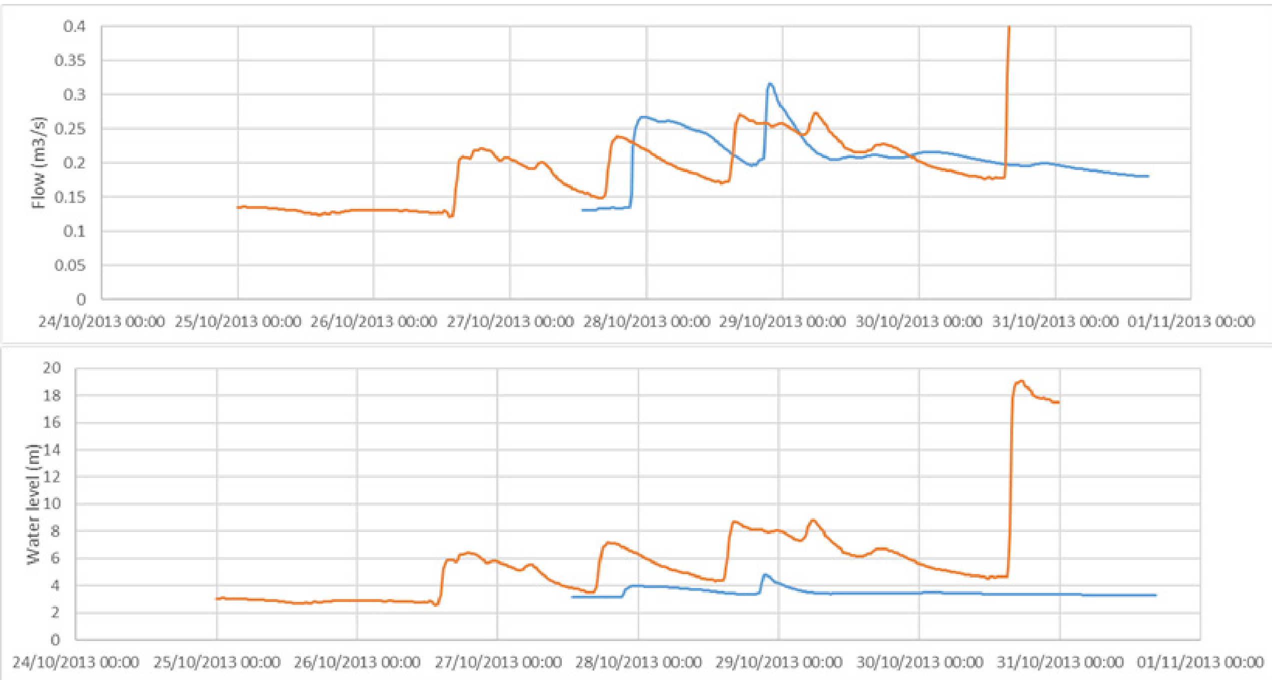


Figure A2.16 Measured (gauge U2H022, orange line) vs simulated flows (blue line) and water levels on the Msunduze (Umgeni) River.

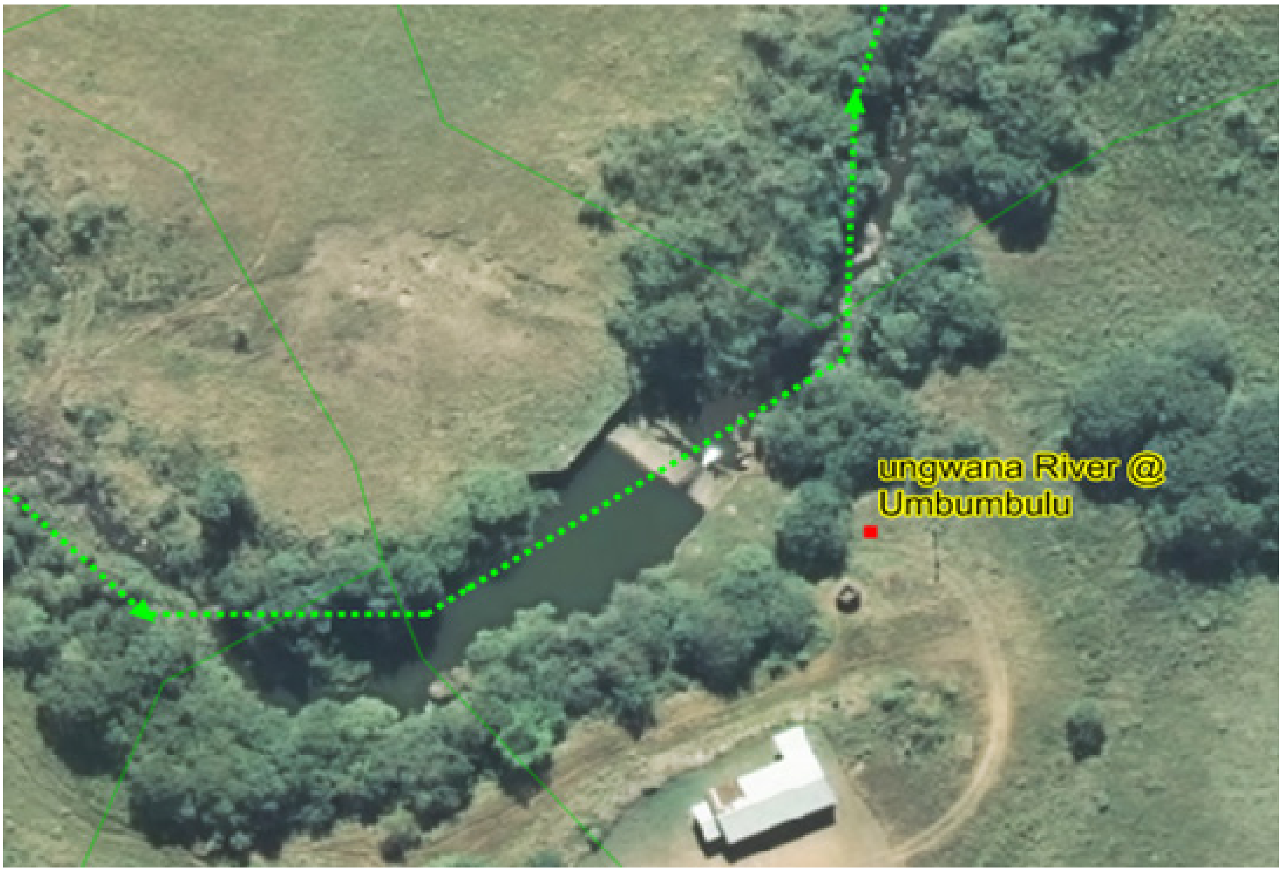


Figure A2.17 Picture of the weir and small dam on the Nungwana River

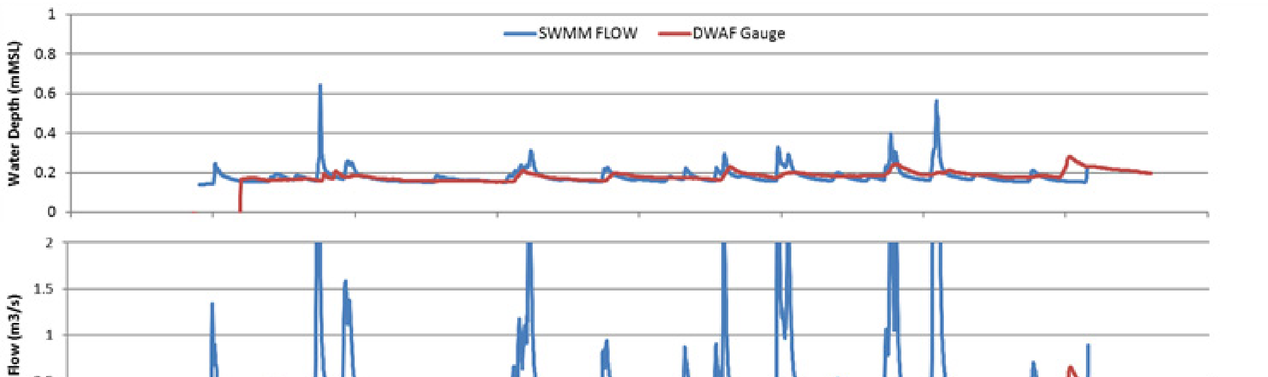


Figure A2.18 Measured (red line) vs simulated flows (blue line) and water levels on the Nungwane River in the south.

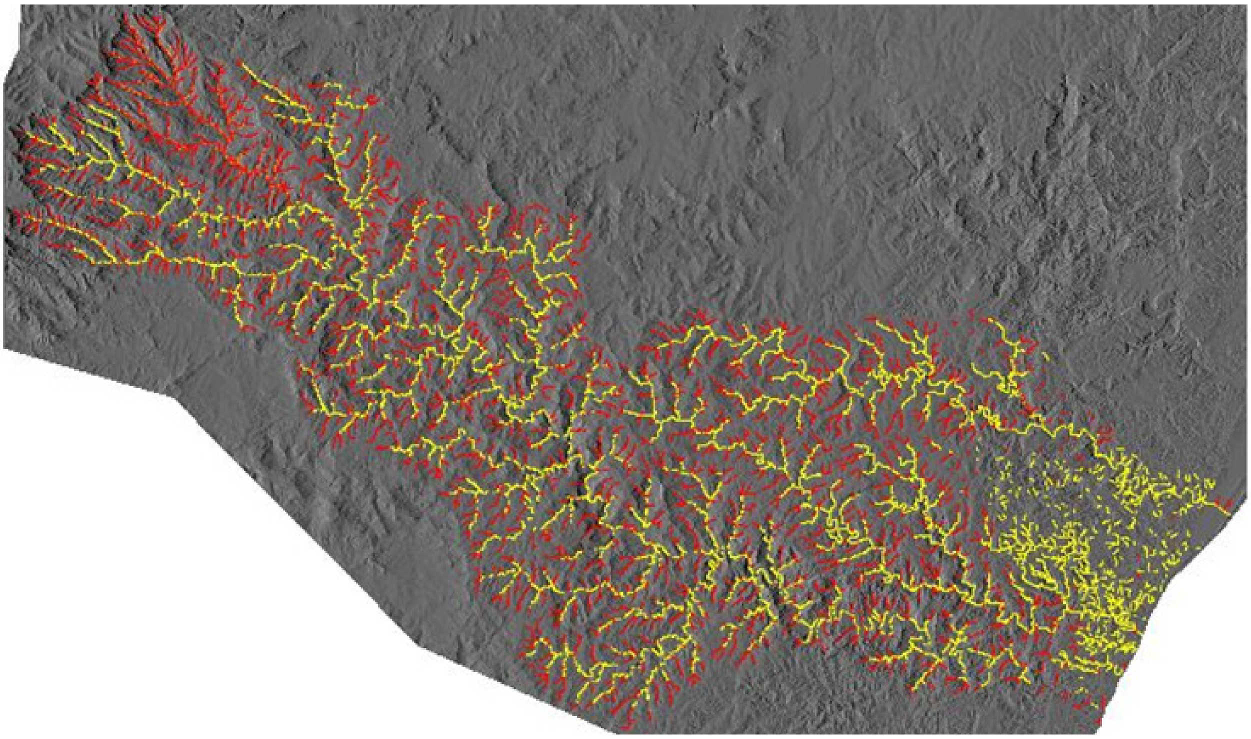


Figure A2.19 The southern EThekwini catchments showing the additional conduits that were included in the model represented by the red lines.

The sensitivity of the model to various hydraulic parameters was tested using the SRTC tool on PCSWMM (Table A2. 12). The sensitivity of the results was tested for the various parameters. The results were most sensitive to changes in the depression storage and % imperviousness. Simulated flood peaks were compared with those estimated by Jezewski in 1984 (Table A2. 13). Jezewski (1984) used a simple rational method approach to estimate the 2-year flood peak flows for the different rivers.

Table A2.12 Sensitivity of runoff volume and peak flow to surface runoff parameters (EPA, 2015).

Parameter	Typical effect on hydrograph	Effect of increase on runoff volume	Effect of increase on runoff peak	Comments
Area	Significant	Increase	Increase	Less effect for a highly porous catchment
Imperviousness	Significant	Increase	Increase	Less effect when pervious areas have low infiltration capacity
Width	Affects shape	Decrease	Increase	For storms of varying intensity, increasing the width tends to produce higher and earlier hydrograph peaks, a generally faster response. Only affects volume to the extent that reduced width on pervious areas provides more time for infiltration.
Slope	Affects shape	Decrease	Increase	Same as for width, but less sensitive, since flow is proportional to square root of slope.
Roughness	Affects shape	Increase	Decrease	Inverse effects as for width.
Depression storage	Moderate	Decrease	Decrease	Significant effect only for low-depth storms.

Table A2.13 Sensitivity of runoff volume and peak flow to surface runoff parameters (EPA, 2015).

Source	Jezewski (1984)			Current SWMM Model (2016)			
				Peak Discharge Q (m³/s)			
River	Area (km2)	Tc (h)	2yr Flood Peak Discharge Q (m3/s)	2yr Return Period	5yr Return Period	10yr Return Period	20yr Return Period
uTongati	436	8.5	69	190	494	831	1151
uMdloti	527	12.5	76	57	197	203	212
oHlanga	118	5.8	36	40	82	113	130
uMgeni	4432	33.6	223	302	668	1033	1463
Durban Bay	242	6.1					
Umbilo				230	364	539	680
Umhlatuzana				366	718	992	1128
Mlazi	972	12.7		1050	2293	3384	4204
eziMbokodweni	295	8.3	57	617	1051	1505	1902
Manzimtoti	44.5	2.8	22	82	160	1	49
Little Manzimtoti	12.5	1.9	11.5	43	64	74	85
iLovu	893	14.3	100	676	1045	1709	1774
uMsimbazi	36.4	2.4	19.5	48	102	132	188
uMgababa	37	2.6	19.8	34	125	198	330
Ngane	16.5	1.8	13.3	35	64	84	109
uMkhomazi	4310	39.0	220	20	103	242	404
uMahlongwane	17	1.4	13.4	6	10	13	16

A2.5.4 Calibration of water quality

Monthly water quality data collected by the EM Water and Sanitation Division were used for calibration and validation of the model. Most of the rivers within the EM are monitored

The water quality measured at the outfalls of the WWTWs were analysed. These values were significantly lower than those provided in the General Effluent Limits. These values were replaced with the average TIN, P and SS values measured at each outfall of the WWTWs (see Table A2. 14).

Table A2.14 Sensitivity of runoff volume and peak flow to surface runoff parameters (EPA, 2015).

WWTWs (River)	Tongaat (Tongati)	Umdloti (Umdloti)	Verulam (Umdloti)	Phoenix (Mhlanga)	Mhlanga (Mhlanga)	Genazzano (Beachbums)	KwaMashu (Mgeni)
TIN (Ammonia, Nitrates and Nitrites) (mg/L)							
min	0.6	0.6	0.0	1.1	0.6	0.0	0.6
max	30.0	25.5	14.5	43.1	48.0	52.9	24.5
average	8.5	4.2	2.5	10.7	11.8	9.2	8.9
summer	9.2	5.1	2.4	10.1	10.3	9.0	7.9
winter	7.8	3.2	2.6	11.3	13.2	9.3	9.7
Orthophosphates (mg/L)							
min	0.0	0.2	0.0	0.5	0.0	0.1	0.2
max	30.0	10.0	14.0	13.0	12.0	11.0	22.0
average	1.4	4.4	1.2	4.0	4.6	4.2	3.4
summer	1.6	4.6	0.8	4.0	4.2	4.1	3.6
winter	1.3	4.4	1.5	4.0	4.9	4.4	3.2
Suspended Solids (mg/L)							
min	0	0	1	0	0	0	0
max	1674	85	2173	56	104	249	55
average	24	6	68	5	9	7	11
summer	36	6	63	6	7	10	10
winter	13	6	74	4	10	4	12
Turbidty (NTU)							
min	3	1	1	1	2	1	3
max	1409	31	4001	57	343	129	4001
average	21	4	170	5	12	5	67
summer	31	4	227	6	9	7	65
winter	11	4	113	5	14	3	67

Simulations were run for a one-week period from the 1 – 7 July 2014 at 2-second time interval. This period was chosen because there was one rainfall event experienced throughout the subcatchment. The results from these simulations are given in Figure A2. 20 and Figure A2. 21 below. The corresponding water quality parameters measured at the same points are provided in Figure A2. 22. Note that the simulated values are within reasonable range of the measured values.

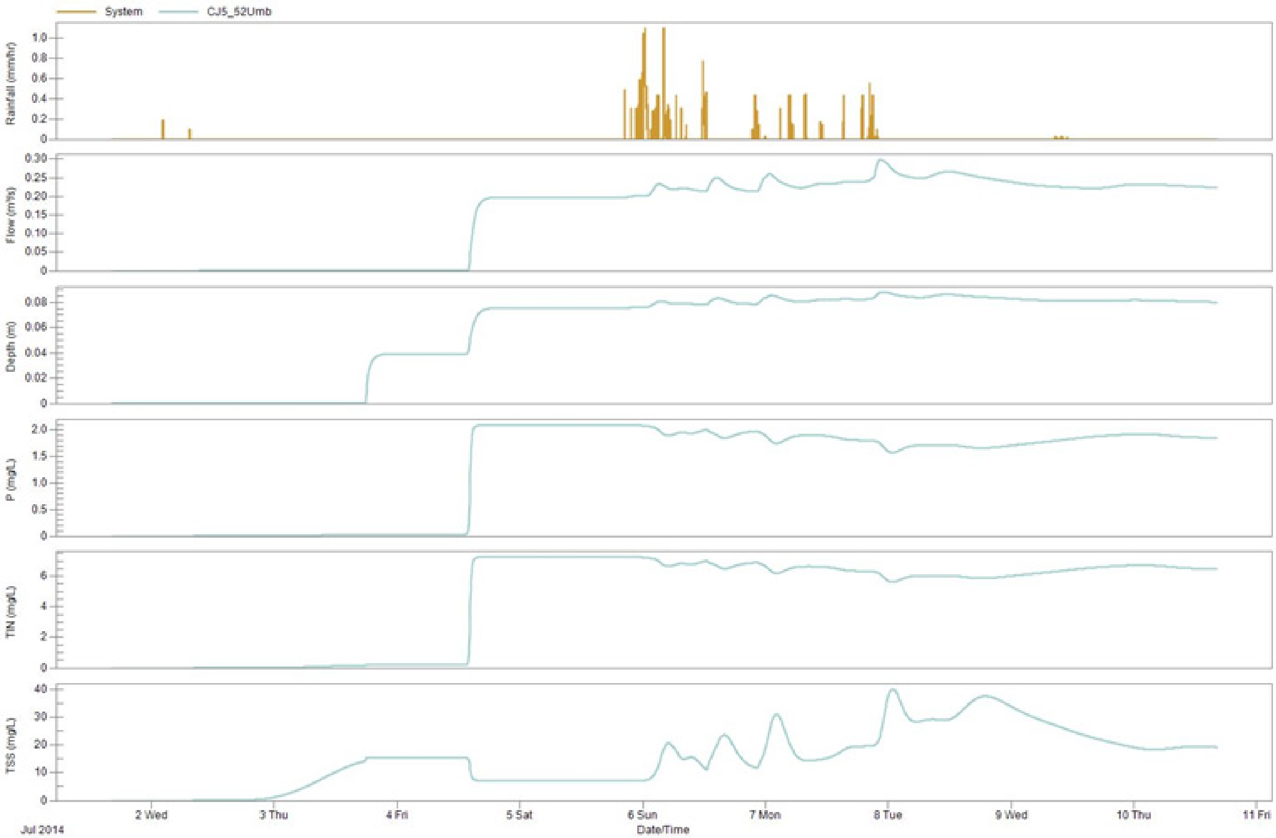


Figure A2.20 Measure rainfall and simulated flow, depth, P, TIN, TSS concentrations for monitoring station (R_ZANA_10) on the Umhlatuzana River.

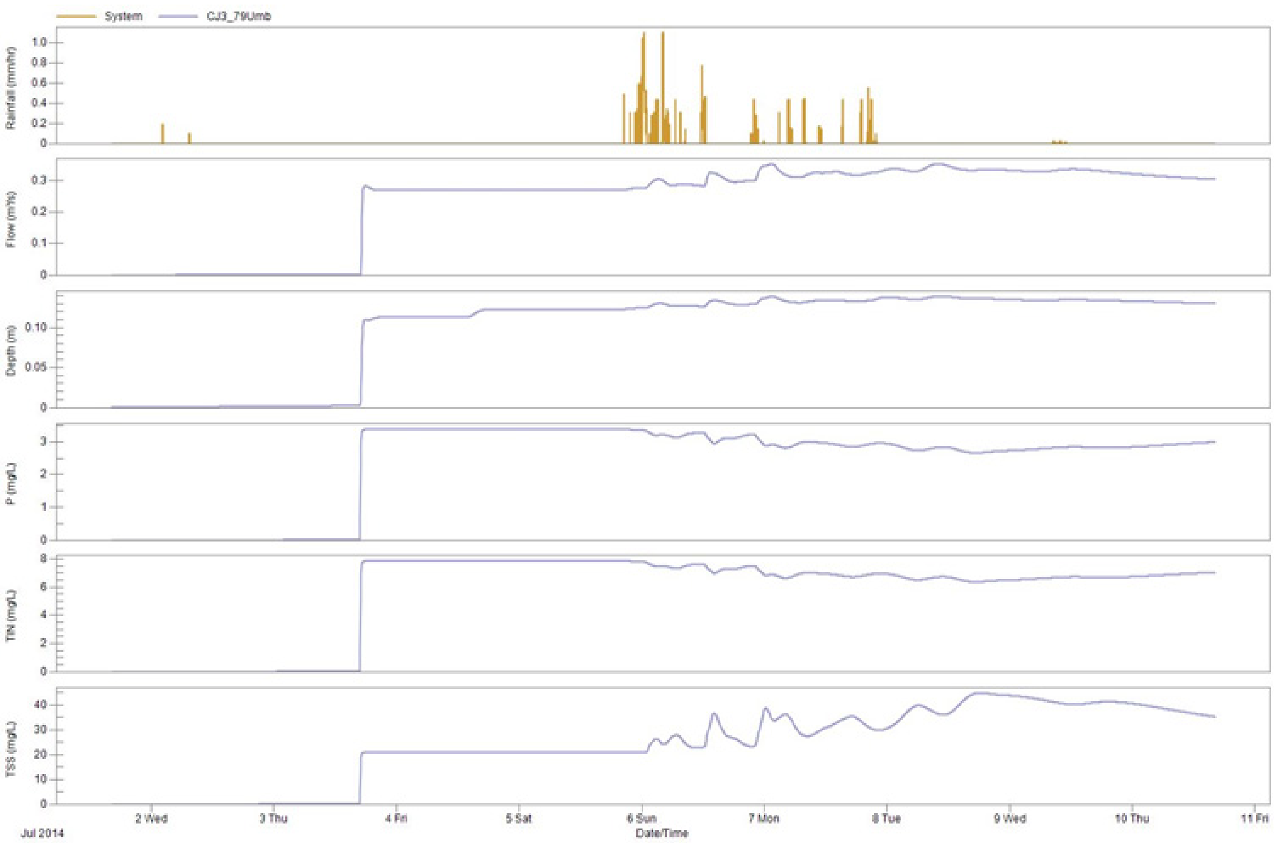


Figure A2.21 Measure rainfall and simulated flow, depth, P, TIN, TSS concentrations for monitoring station (R_UMBILO_13) on the Umbilo River.

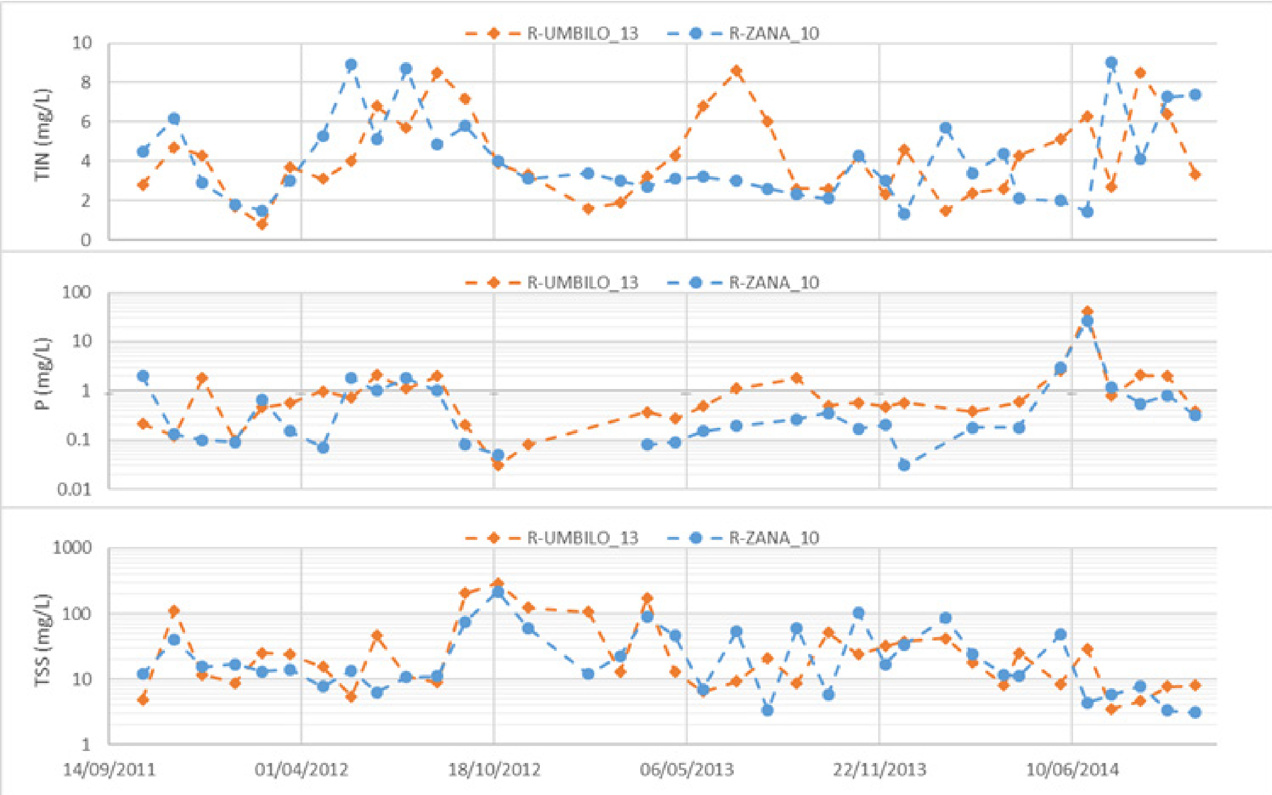


Figure A2.22 Figure A2. 22. Measured water quality from water sampling stations on the Umbilo and Umhlatuzana Rivers at the same locations as the simulations.

A2.6 Assumptions and Limitations

A number of assumptions were made during the setup of the SWMM model where input data were either insufficient or unreliable. These assumptions may be regarded as limitations of the model and therefore should be considered when analysing the results.

The use of design rainfall
Note that design rainfall assumes that rainfall is equally distributed over the whole catchment at the same time. Realistically, a specific design rainfall does not imply an equal design runoff, however this is general practice when performing flood studies.

Groundwater and baseflows
Groundwater was not included in the modelling. Insufficient data were available to incorporate any accurate representation of groundwater flows. Therefore, measured flow/water level data was used to infer the groundwater as baseflow. Groundwater inputs vary seasonally, therefore the 'baseflow' was estimated during summer and winter periods and incorporated into the model as a time series where possible.

Stormwater network data
The current stormwater network data were inconsistent and incomplete. Only certain areas of the current SMS audit have been completed and were included in the model, however inconsistencies and errors were also found in these networks. Missing data were entered based on the following assumptions:

- pipe sizes: a default value of 0.375 m
- invert levels: levels were taken from the DEM and the profile was altered in order to acquire a reasonable slope

The model was run numerous times in order to resolve flooding and continuity issues resulting from problems with these data. Invert levels were manually adjusted in order to correct negative slopes.

Calibration data
The water quality monitoring program takes measurements on a monthly basis. This data therefore provides a snapshot of the water quality at a point at a specific time. TSS concentrations were inferred from turbidity data collected by the EM. The relationship between TSS and turbidity was taken from data collected by Newman (2015) in the Durban Bay, which has a high salinity. TSS concentrations are temporally and spatially dependant and therefore this is not a true representation of actual TSS concentrations. We recognise that this a major limitation in the estimation of measured TSS loads used for calibration.

TIN, P and suspended solids concentrations from the WWTWs was averaged and added into the model as a point source at the outfall site of the relevant WWTWs. The discharge rates were assumed to be equal to the design capacity and is therefore not a true representation of actual discharge rates and quality.

Generalised event mean concentrations (EMC) were based on values derived in the United States.

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APPENDIX 3: INFRASTRUCTURE COST ESTIMATE METHOD

A3.1 Overview

This section describes the cost estimation method. The method estimates the existing infrastructure costs from their dimensions. It then uses a scaling relationship between flow and the infrastructure dimensions to estimate the stormwater requirements under the different land use scenarios. The infrastructure required to satisfy the various scenarios are then costed. The cost difference between the existing infrastructure and the scenario infrastructure is indicative of the value of the natural areas.

A3.2 Identifying Existing Infrastructure

An inventory of all the stormwater infrastructure is identified and categorised into four major categories: bridges; canals; culverts and pipe networks. The bridges are divided into a further two subcategories: bridge culverts and bridge pipes. The bridge category excludes major bridges as their size is insensitive to flows.

A3.3 Assigning Rainfall Return Periods

Each infrastructure category is assigned a design return period based on the eThekwini Design Guidelines (eThekwini Municipality 2008). Table A3. 1 shows the return periods associated with the relevant infrastructure category. The design rainfalls are then modelled to estimate the peak flows for each structure.

Table A3.1 Return periods assigned to each of the infrastructure categories

Category		Return Period (years)
Bridges	Bridges Culverts	20
	Bridges Pipes	20
Canals		10
Culverts		5
Pipes		2

A3.4 Cost Estimate of the Infrastructure

Costs are estimated for each of the four categories as each contains different assumptions. Material costs are based on 2016 prices with delivery to central Durban. All prices include a 10% mark-up and exclude value added tax (VAT). Labour rates are legislated for the Civil Construction industry and were taken as R27/hr. All infrastructure was assumed to be under road ways and the reinstatement was estimated to be R420/m^2. Excavation was taken as R90/m^3, selected backfill as R80/m3 and backfill at R60/m3. The supply and placing of concrete was estimate at R2400/m^3, shuttering was assumed to be R650/m^2 and the supplying and fixing of steel was taken as R12000/t. Concrete blinding was estimated as R1600/m^3. A 10-20% allowance on the total cost was provided for preliminary and general items (P&G) such as site establishment and supervision. The individual rates for each infrastructure category are summarised in additional information.

A3.4.1 Bridges

Bridges have two subcategories: bridge culverts and pipe culverts. Bridges differ from the culvert and pipe categories as they are positioned within watercourses. To allow for the complications of dealing with water the P&G was set to 20%. With the exception of not having manholes the bridge culverts and the pipe bridges are priced the same as the culverts and the pipes respectively.

A3.4.2 Culverts

Culverts are defined as any non-circular structure not acting as a bridge. The culvert costs are estimated from the cross-sectional area and the length. It is assumed that all the culverts are constructed from 0.3 m thick insitu reinforced concrete with steel reinforcing attributing to 4% of the total volume. It is assumed that all the ground conditions are the same and that the structures are founded on 200 mm of concrete blinding. Excavation quantities are based on 600 mm of cover and a payment width as defined in Clause 5.2 of SANS 1200DB. Manholes were priced as R25 000 each and one was assumed every 60 m.

A3.4.3 Canals

Canals are priced the same as culverts except there are no roof slabs, cover material or manholes.

A3.4.4 Pipes

The pipe costs are calculated similarly to the culvert costs. It is assumed that all the ground conditions are the same and that a Class B bedding (Drawing LB-1, SANS 1200LB) is used throughout. Excavation quantities are based on 600 mm of cover and a payment width as defined in Clause 5.2 of SANS 1200DB. Manholes were priced as R25 000 each and one was assumed every 60 m.

A3.5 Flow vs Dimension Relationship

To estimate the changes in cost a relationship between flow and the infrastructure dimensions needs to be established. These flow relationships can be established theoretically for diameter and area from uniform flow conditions. The relationship is then used to scale the infrastructure dimensions for the different scenario flows. A scaling relationship exists for open channel flows and pressurised flows. Both of these flow types are estimated for each flow scenario.

A3.5.1 Pipe Scaling

The scaling relationship for pipe diameters in open channel flow is

$$D = D_0 \left(\frac{Q}{Q_0}\right)^{\frac{2}{5}}$$

and the scaling relationship for pressurised flows is

$$D = D_0 \left(\frac{Q}{Q_0}\right)^{\frac{1}{2}}$$

,where D is the scaled diameter, D_0 is the existing pipe diameter, Q is the scenario flow and Q_0 is the flow under the existing conditions (status quo).

A3.5.2 Culvert Scaling

The scaling relationship for culvert area in open channel flow is

$$A = A_0 \left(\frac{Q}{Q_0}\right)^{\frac{4}{5}}$$

and the scaling relationship for pressurised flows is

$$A = A_0 \left(\frac{Q}{Q_0}\right)$$

,where A is the scaled area, A_0 is the existing culvert area, Q is the scenario flow and Q_0 is the flow under the existing conditions (status quo). The culvert width is then determined by dividing the scaled area, A, by the culverts original height.

A3.5.3 Estimating the Flow Type

To determine which scaling relationship is to be used the flow type needs to be estimated. The flow type is estimated by calculating the infrastructure's maximum open channel flow from the Mannings equation.
This flow is referred to as the threshold flow and it is calculated from

$$Q_{threshold} = \frac{1}{n}\frac{a^{\frac{5}{3}}}{P^{\frac{2}{3}}} S_0^{\frac{1}{2}}$$

Where n, the Mannings roughness, is assumed to represent concrete at a value of 0.015. a is the cross-sectional area, P is the perimeter and S_0 is the slope of the infrastructure.

If the scenario flow, Q, is less than the threshold flow the open channel scaling is used. If the scenario flow exceeds the threshold flow then the pressurised scaling is used.

Two other conditions are included to ensure that the scaling does not artificially inflate the benefit of the natural areas. If the scenario flow does not exceed the threshold flow and the existing flow then no scaling is applied. If the scenario flow exceeds the threshold flow but does not exceed the existing flow then the open channel scaling is applied. These conditions ensure that scenario flows that are larger than the existing flows but that do not require larger infrastructure are not scaled. This means that artificial benefits are not attributed to the natural areas. It also ensures that the cost of over design and future capacity are not penalised.

The followings is a summary of all the conditions relevant to the scaling:

Condition 1:
If $Q > Q_{threshold}$
then $D = D_0 \left(\frac{Q}{Q_0}\right)^{\frac{1}{2}}$ or $A = A_0 \left(\frac{Q}{Q_0}\right)$

Condition 2:
If $Q < Q_{threshold}$ and $Q < Q_0$
then $D = D_0 \left(\frac{Q}{Q_0}\right)^{\frac{2}{5}}$ or $A = A_0 \left(\frac{Q}{Q_0}\right)^{\frac{4}{5}}$

Condition 3:
If $Q < Q_{threshold}$ and $Q \geq Q_0$
then $D = D$ or $A = A$

A3.6 Cost Comparison

The difference between the existing infrastructure costs and the scenario infrastructure costs are the indicative value of the natural areas.

A3.7 Additional information

The items included for the costing of each category are shown in Table A3. 2, Table A3. 3, Table A3. 4, Table A3.5. Table A3. 6 shows the linear meter cost of concrete stormwater pipes.

Table A3.2 Construction rates applied to the bridge culvert category

Description	Unit	Rate
Excavation	m^3	R 90.00
Selected fill	m^3	R 80.00
Backfill	m^3	R 60.00
Blinding	m^3	R 1 600.00
Shuttering	m^2	R 650.00
Steel	t	R 12 000.00
Concrete	m^3	R 2 400.00
Reinstatement	m^2	R 420.00
Preliminary and general items	%	20

Table A3.3 Construction rates applied to the bridge pipe category

Description	Unit	Rate
Pipe	m	Refer to Error! Reference source not found.
	m^3	R 80.00
Excavation	m^3	R 90.00
Bedding	m^3	R 320.00
Concrete	m^3	R 2 400.00
Reinstatement	m^2	R 420.00
Preliminary and general items	%	10

Table A3.4 Construction rates applied to the canal and culvert category

Description	Unit	Rate
Excavation	m^3	R 90.00
Selected fill	m^3	R 80.00
Backfill	m^3	R 60.00
Blinding	m^3	R 1 600.00
Shuttering	m^2	R 650.00
Steel	t	R 12 000.00
Concrete	m^3	R 2 400.00
Reinstatement	m^2	R 420.00
Preliminary and general items	%	10

Table A3.5 Construction rates applied to the pipe category

Description	Unit	Rate
Pipe	m	Refer to Error! Reference source not found.
Excavation	m^3	R 90.00
Bedding	m^3	R 320.00
Selected fill	m^3	R 80.00
Backfill	m^3	R 60.00
Manholes	m^2	R 25 000.00
Reinstatement	m^2	R 420.00
Preliminary and general items	%	10

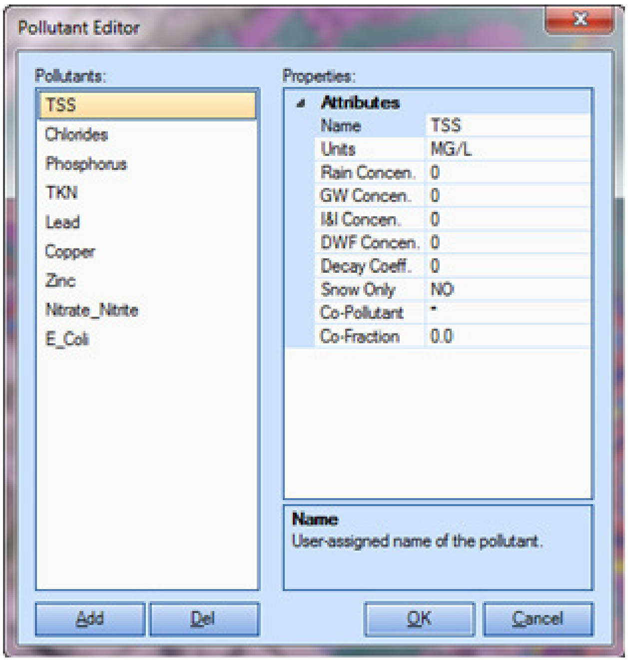
Table A3.6 The cost of pipes in 2016 delivered to central Durban

Diameter (m)	Rate (R/m)	Diameter (m)	Rate (R/m)
0.3	313.50	0.9	1383.80
0.375	424.60	1.05	1777.60
0.45	555.50	1.2	2284.70
0.525	641.30	1.35	2649.90
0.6	1136.30	1.5	3634.40
0.75	1060.40	1.8	5195.30
0.825	1204.50		

APPENDIX 4: SEDIMENT AND NUTRIENT MODELLING

A4.1 Introduction

The contribution and retention of natural areas to nitrogen (TIN), phosphorous (P) and sediment loads (TSS) was determined under two different scenarios. These two scenarios were chosen in order to provide a range of what the water quality changes would be considering a conservative and a worse case assumption.



A4.2 Model setup

The water quality parameters chosen for this study were nutrients (nitrogen, phosphorous) and total suspended solids (TSS). The input parameters for each pollutant are as follows:

- the pollutant name
- the concentration units (i.e. mg/L, µg/L, counts/l)
- concentration in rainfall
- concentration in groundwater
- concentration in direct infiltration/inflow
- first-order decay coefficient
- It is possible to assign a co-pollutant as a fixed fraction of the runoff concentration of the main pollutant. However, this was feature was not used.

The landuses that generate these pollutants were defined and the pollutant buildup, pollutant washoff and street cleaning parameters were assigned to each landuse. Note that no data was available to estimate the pollutant buildup and street cleaning parameters and therefore these features were not considered. The pollutant washoff from a given land use occurs during periods of wet weather and can be characterized in SWMM5 by either using an exponential or rating curve relationship. The Event Mean Concentration (EMC) is a case of Rating Curve Washoff where the exponent is 1.0 and the coefficient represents the washoff pollutant concentration in mg/L. In each case pollutant buildup is continuously depleted as washoff proceeds, and washoff ceases when there is no more buildup available. The EMCs were derived from literature (Table A4. 1). These data were applied to the different landuse categories across the study area. The data below can be applied in determining the water quality volume to be catered for in stormwater management devices (e.g. SUDS).

Table A4.1 Event Mean Concentration data used in water quality modelling.

Landuse Description	TSS (mg/l)	BOD (mg/l)	TIN (mg/l)	P (mg/l)
Settlement - urban	100	15	3.41	0.79
Commercial / Retail / Institutional	166	9	2.1	0.37
Industrial / Road & Rail	166	9	2.1	0.37
Extractive / Utility	166	9	2.1	0.37
Farming / plantations & woodlots	201	4	1.56	0.36
Recreational open space	201	4	1.56	0.36
Settlement - rural	201	4	1.56	0.36
Natural vegetation (D'MOSS)	70	6	1.51	0.12
Settlement - informal	497		22	6.7

The TSS load estimated in PCSWMM accounts for the total suspended sediments generated due to catchment runoff and does not account for the proportion of sediment transport activated from the river bed (i.e. the bedload). While bedload transport is the dominant mode for low velocity flows and/or large grain sizes, suspended load transport is the dominant mode for high velocity and/ro fine grain sizes (Chadwick et al., 2013). In South Africa, a factor of 1.25 is generally applied to cater for bed load and non uniformity in suspended sediment concentrations in order to estimate the mean annual sediment load (Msadala et al. 2010, after Rooseboom 1992). Cooper (1993) referenced estimates of the proportion of bedload in KwaZulul-Natal rivers from other studies to range from 12 to 50%.

A4.2.1 Pollutant reduction through dams

Routing river flows through dams is a fairly complex exercise. There are a number of large dams in the EMA. Therefore, in order to provide continuity through these dams and best represent the impacts of dams on flood flows, the model was split by routing all the flows entering the dam to an outfall. The model was then started again downstream of the dam. The simulated outputs for estuaries with dams situated upstream therefore only represent the catchment yield downstream of the dam.

The TIN and P loads were assumed to be conserved through the dams and therefore the total TIN and P loads into the dams were added to the estimated loads at the respective estuaries situated downstream of these dams. Cooper (1993) suggested that dams in uMgeni River catchment reduce sediment yield, and in particular bedload, to the coast. TSS removal through dams was estimated based on the equation given by Fair et al. (1958) and tested by Kuo (1976), where

$$EFF = 1 - \left(1 + \frac{V_s}{n * \frac{Q}{A}}\right)^{-n}$$

where EFF is the Removal Efficiency Factor i.e. fraction of TSS load which is deposited in the tank/basin or removed by other means, V_s is the particle settling velocity (m/s), typically between 0.00011 and 0.00058 m/s, n is the turbulence factor, where n = 1 means significant, n = 5 is low turbulence, Q is the inflow and A is the surface area of the basin.

Water quality data for the WWTWs were taken from measurements taken by the EM at the respective WWTWs outfalls, where TIN = ammonia + nitrates + nitrites, P = orthophosphates and TSS = suspended solids. The average concentration was calculated for each pollutant.

A4.2.2 Rainfall

Real-time rainfall data was applied to the models as described in Appendix 2. The simulations were run from 1 August 2013 until 30 July 2014. Note that sediment yields vary spatially and temporally and therefore a one year simulation is not indicative of the mean annual sediment yield. The annual rainfall (572 mm for Durban city central) experienced during this period was below the MAP of Durban (1000 mm) and therefore simulated results are conservative. Note that Rooseboom and Lotriet (1992) suugest that six years of continuous mintitoring is requied to obtain a reasonable estimate of the average sediment load of a typical South African river.

A4.3 The impact of natural systems on water quality

Two scenarios were simulated to provide an indication of the impacts of the loss of natural areas on sediment and nutrient loads entering surface waters and an estimation of the water quality amelioration benefit obtained by retaining these natural systems.

The first hypothetical scenario describes a situation without the pollutant retention benefits of natural vegetation. The pollutant retention function of green areas was 'switched off' to provide an estimate of the ecosystem services provided by natural elements of the landscape. This is considered to be a conservative approach as it did not require any assumptions of how the landuse would change under different development scenarios.

The EMC of the different pollutants were altered for natural vegetation based on the pollutant loading reduction factor (Table A4. 2). For example, if grass areas are estimated to reduce pollutant loadings by 50%, we assumed that the EMC from that type of landuse was double the EMC ascribed to that landuse.

Table A4.2 Assumed pollutant reduction (%) based on 0.5-year return period event (Georgia 2015).

Approach	TSS	TIN	Total P
Grass channel	50	20	25
Gravity oil / grit separator (industrial areas)	40	54	5
Permeable paving	80	50	50
Stormwater pond	80	30	50
Revegetation / reforestation	80	25	50
Vegetated filter strip	60	20	20

The results from the second hypothetical scenario determine the impacts on water quality if all conservations areas (D'MOSS areas) were replaced by dense rural informal settlement. This scenario provides a worst case scenario as changing the landuse from natural vegetation to dense informal settlement has a dual negative impact, i.e. informal settlements are associated with a high event mean concentration of pollutants and the removal of natural vegetation reduces the uptake of nutrients and sediments. The landuse file was edited and all natural vegetation was replaced with rural informal settlement. The area weighting tool was used to import the new shapefile into SWMM with the corresponding changes in hydraulic, soil and water quality properties associated with the change in landuse.

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APPENDIX 5: WATER TREATMENT COST ANALYSIS

A5.1 Introduction

Both high sediment and nutrient loads lead to increased water treatment operation and maintenance costs. Increases in sedimentation and associated increases in turbidity in river systems have become a common challenge facing many cities worldwide (McDonald & Shemie 2014). Changes in turbidity affect more than just the river ecosystem but also shorten the life span of storage dams, increase water treatment costs and change the nature of coastal areas (McDonald & Shemie 2014). Cities with lower than average forest cover and a higher amount of agriculture within the catchment generally have the highest levels of sediments and nutrients entering aquatic systems (McDonald & Shemie 2014). An accumulation of the essential plant nutrients, nitrogen and phosphorous, in rivers and dams can cause excessive algal growth and can lead to algal blooms. In most freshwater systems, phosphorous is the limiting nutrient for plant growth and large increases in phosphorous entering waterways can lead to algal blooms. Phosphorous is found in a number of common items such as fertilizer, manure, detergent, human waste and decaying plants, all of which enter waterways through agricultural and urban runoff, poor sanitation within the catchment and industrial discharges. During high rainfall events the amount of total phosphorous entering rivers and dams increases resulting in the potential for algal blooms and increased water treatment costs.

In the context of treating water the biggest effects of increased sediment and nutrient loads on the cost of treating water are listed below (Source: Graham 2004, McDonald & Shemie 2014, Rangeti 2014):

- Increased usage of coagulants;
- Increased amount of time water spends in settling ponds;
- Increased wastewater sludge (costly to treat and transport);
- Increased sediment loads preventing adequate filtration and disinfection of other pathogens and algae;
- Increased occurrence of algal blooms and toxic algae;
- Increased dominance by blue-green algae;
- Clogging of reticulation systems by filamentous algae;
- Increased occurrence of taste and odour issues in potable water and the need for activated carbon usage to eliminate these;
- Wasted water on more frequent backwashing to clean clogged filters; and
- Increased nutrients require the use of more complex and costly treatment technologies.

A5.2 Water treatment in eThekwini Municipality

The eThekwini Municipality receives bulk potable water from Umgeni Water, a National Government Business Enterprise and the largest water supplier in KwaZulu-Natal accounting for a total bulk water sales volume of 423 million kilolitres per annum and serving a total of 6.1 million people (Umgeni Water 2015). Umgeni Water extracts the raw water from a number of dams within the uMngeni Basin that are linked to water treatment works throughout the province. Two of the largest water treatment works in the province are located in the EMA. Raw water from Nagle Dam is supplied to The Durban Heights WTW (Figure A5. 1) which produces 523 ML or 42% of Durban's potable water and raw water from Inanda Dam supplies water to Wiggins WTW which produces 267 ML or 21% of the city's potable water. Once the water is treated, it is reticulated to domestic and industrial consumers within the EMA. Although the bulk water is purchased from Umgeni Water who run the WTW's, the bulk distribution and downstream pipelines are owned and operated by the eThekwini Municipality.

Figure A5.1 Durban Heights WTW with a capacity of 615 Ml/day is the largest WTW operated by Umgeni Water and is located within the EMA (Source: Umgeni Water)

The water treatment process at Durban Heights and Wiggins WTW are very similar and involves a number of different physical and chemical treatment methods, such as filtration and coagulation. The principle objective of treating water is to produce water at a reasonable cost and in a reliable manner that is fit for domestic use (Rangeti 2014). However, chemical dosage and operating costs at WTWs depend primarily on the quality of the raw water abstracted from the dams with temporal variation having large influences on these costs (Graham et al. 2012). Within a conventional water treatment process coagulants, disinfectants, oxidants and pH adjusters are used throughout. In the first step of the treatment process the water abstracted from the dams passes through wire screens to remove any solid objects. The water is then pre-treated using chlorine as a disinfectant, inactivating any disease causing pathogens and reducing odour, colour and taste problems (Rangeti 2014). The level of the pH in the raw water is adjusted to create an optimum environment for effective coagulation. Lime (calcium carbonate, calcite or CaCo3) is most often used to adjust the pH. Following this, a process of mixing, coagulation and flocculation processes occur whereby a coagulant is used to coagulate unwanted particles and algae into larger flocs, which then sink to the bottom of the sedimentation tank (Graham 2004, Rangeti 2014). At Durban Heights and Wiggins WTW, a polyelectrolyte (a man-made organic compound) is used as a coagulant in the treatment process because of its effectiveness over a wide range of pH thus reducing pH adjustment costs and because it has low water retention capacity it also reduces floc disposal costs (Rangeti 2014). The clear water is then passed through large filters that remove any remaining suspended matter. The final step is the post-treatment disinfection process that uses chlorine to kill any remaining pathogens and unwanted algae. The treated water is then held in reservoir tanks and pumped to industrial and domestic consumers throughout the EMA. Table A5. 1 outlines the operating characteristics of Durban Heights and Wiggins WTWs.

Table A5.1 Operating characteristics for Durban Heights and Wiggins WTWs (Source: Umgeni Water)

Landuse Description	TSS (mg/l)	BOD (mg/l)
River system	Lower uMngeni	Lower uMngeni
Areas serviced	Northern areas of EMA: e.g. Newlands, KwaMashu, Ntuzuma, Phoenix, Durban North & Umhlanga	Southern areas of the EMA: e.g. Woodlands, Isipingo, Lotus Park, Amanzimtoti & KwaMakuta areas
Maximum capacity	615 Ml/day	350 Ml/day
Current utilisation	497 Ml/day	258 Ml/day
Pre-oxidation type	Prechlorination	Ozone
Primary pre-treatment chemical	Polymeric coagulant	Polymeric coagulant
Clarifier type	Pulsator clarifier	Pulsator clarifier
Number of clarifiers	18	4
Filter type	Constant rate rapid gravity filters	Constant rate rapid gravity filters
Number of filters	100	24
Capacity of backwash water tanks	2326 m3	-
Capacity of sludge treatment plant	30 000 kg/day thin sludge	-
Post disinfection type	Chlorine gas	Hypochlorite

A5.3 Current state of the uMngeni River Catchment Area

The uMngeni River is one of the most developed catchments in South Africa and regionally is an area of major economic, cultural and ecological importance (WRC 2002). The uMngeni River originates in the uMngeni Vlei in the highlands of the KwaZulu-Natal Midlands, approximately 1900m above sea level (Graham 2004). The river flows through the KwaZulu-Natal Midlands, Howick, Pietermaritzburg, the Valley of a Thousand Hills and down into Durban emptying into the Indian Ocean just north of Durban Bay. Major tributaries include the Karkloof, Lion, uMsunduze and the Mqeku rivers. There are approximately 130 registered dams in the uMngeni catchment but there are five that are large and of significance in terms of water supply; Midmar, Albert Falls, Nagle, Henley and Inanda Dam having a combined capacity of 753 million cubic meteres of water (WRC 2002). These resevoirs supply the major Pietermaritzburg-Durban complex, home to about 45% of the provincial population (Graham 2004).

The water quality in the uMngeni River is generally fair upstream and deteriorates significantly as the river moves towards the coast passing through a number of large urban and peri-urban centres. The major management concerns include pollution from overflowing sewers, pollution from informal settlements, illegal discharges, industrial discharges, solid waste pollution, overgrazing causing increased erosion, agricultural runoff and alien vegetation in the riparian zone (Dennison & Lyne 1997, Graham 2004, Rangeti 2014). Many of these issues are a result of rapid urbanisation throughout the catchment and all influence nutrient enrichment and sedimentation levels in the uMngeni River and associated water supply dams. The Lower uMngeni System serves the greater eThekwini Municipal Area, deriving potable water from Nagle and Inanda Dams which are supported by Albert Falls and Midmar Dams further upstream (Umgeni Water 2015). Nagle Dam with a capacity of 24.6 million m3, although located outside of the EMA, supplies water to Durban Heights WTW and Inanda Dam with a capacity of 251.6 million m3 supplies water to Wiggins WTW, both of which are located within the boundaries of the EMA (Umgeni Water 2015).

A5.4 Data and methods

Umgeni Water has an extensive water quality monitoring programme that covers all of its WTWs and supply dams. The modelling of nutrient and sediment levels against various cost data was based on water quality, volume, chemical dosage and cost data supplied by Umgeni Water for Durban Heights and Wiggins WTW for a five year period from 1 July 2010 – 30 June 2015. Water quality data was supplied for the raw water entering the treatment works as well as water quality data for the final potable water. This data included all water quality parameters measured at the WTWs such as turbidity, alkalinity, pH, algal counts, iron, nitrates etc. Chemical dosage and related costs were also supplied for the same period and outlined the amount of each type of chemical used during different stages of the treatment process and the associated individual and overall costs. Daily water volume data for both treatment works was supplied for the same period.

The water quality parameters measured in the raw water at the WTWs did not include phosphorous or total nitrogen. These parameters are measured bi-monthly at a monitoring station in the water supply dams and in the uMngeni River above the dams and only the quantity of different types of algae are measured in the raw water entering the WTW. Total Phosphorous (TP), Nitrate, Nitrite and Ammonia are measured in the uMngeni River and water supply dams and this data was used to determine the link between Nitrogen and Phosphorous and algae in the treatment water so as to determine the treatment cost savings involved in the reduction of these nutrients into the water supply dams. Water quality data for monitoring sites on the uMngeni River above Nagle and Inanda Dam were provided for the same five year period to assess the water treatment cost savings associated with reduced nutrients entering the supply dams. River volume and flow data was downloaded from the Department of Water Affairs (DWA) interactive website for water monitoring stations above the dams. Table A5. 2 and Table A5. 3 provide the summary statistics for the Durban Heights and Wiggins WTW model sample data.

Table A5.2 Summary statistics of water quality, volume and cost data from July 2010 – June 2015 from Durban Heights WTW.

Variable	Min	Mean	Max	Variable	Min	Mean	Max
Treatment Cost (R/ML)	40	72	148	Oscillatoria	0.0	47.5	523.0
Volume (ML)	11 482	15 434	17 992	Ceratium	0.0	10.7	51.5
Total Algal Count (cells/mL)	126	955	8 016	Chlamydomonas	0.0	25.3	111.8
Alkalinity (mg CaCO3/L)	29	36	44.7	Chlorela	0.0	5.8	43.0
Colour (°H (mg Pt-Co/L)	1.1	4.8	36.3	Coelastrum	0.0	133.1	545.0
E.coli (MPN/100mL)	0.0	8.3	115.3	Crucigenia	0.0	28.3	455.0
Coliforms (MPN/100mL)	77	1 146	4 839	Cryptomonas	0.0	22.9	137.0
Turbidity (NTU)	2.7	6.1	21.1	Cyclotella	0.0	62.3	515.1
TOC (mg/L)	1.6	2.8	4.7	Cymbella	0.0	7.7	54.0
Suspended Solids (mg/L)	2.1	6.5	42	Dictyosphaerium	0.0	16.7	547.0
pH	7.4	7.8	8.2	Fragileria	0.0	446.2	6869.9
Conductivity (mS/m)	10	13.1	17.4	Pandorina	0.0	47.0	339.7
Temperature (°C)	15	21.1	31	Oocystis	0.0	26.2	127.0
Fe (mg/L)	0	0.1	0.9	Scenedesmus	0.0	41.3	241.2
Algal genera (cells/mL):	Quadrigula	0.0	27.6	290.7			
Anabaena	0	53.2	1571.7	Sphaerocystis	0.0	81.5	717.0
Microcystis	0	121.4	1331.3	Melosira	0.0	89.8	362.0

Table A5.3 Summary statistics of water quality, volume and cost data from July 2010 – June 2015 from Wiggins WTW.

Variable	Min	Mean	Max	Variable	Min	Mean	Max
Treatment Cost (R/ML)	34	67	130	Total Algal Count	20	1954	14601
Volume (ML)	7093	9075	17992	E.coli (MPN/100mL)	0.0	1.4	30.4
Alkalinity	48.6	60.5	68.1	Coliforms (MPN/100mL)	66.5	1731.8	5000.0
Colour (°H (mg Pt-Co/L)	1.4	3.1	10.9	Algal genera (cells/mL):			
TOC (mg/L)	1.91	3.23914	5.79	Microcysitis	0.0	512.2	12404.6
Turbidity (NTU)	0.5	1.2	2.3	Anabaena	0.0	16.4	388.5
TOC (mg C/L)	1.9	3.2	5.8	Chlamydomonas	0.0	21.5	159.0
Suspended Solids (mg/L)	2.2	4.6	9.3	Cryptomonas	0.0	22.2	80.0
pH	7.3	7.8	8.8	Cyclotella	0.0	23.1	267.5
Conductivity (mS/m)	19.1	24.9	27.9	Fragilaria	0.0	874.3	7038.3
Temperature (°C)	15.5	21.3	26.3	Melosira	0.0	39.8	268.0
Iron (mg/L)	0.0	0.1	0.8	Quadrigula	0.0	14.6	372.0
Manganese (mg/L)	0.01	0.03	0.12	Ceratium	0.0	19.9	147.0
Fluorine (mg/L)	99.0	140.4	183.0	Scenedesmus	0.0	100.7	967.8

Water treatment cost models were estimated for Durban Heights WTW and Wiggins WTW based on data provided by Umgeni Water. Durban Heights is the largest water treatment works and Wiggins is the second largest in the EMA supplying two thirds of the municipalities water and therefore formed the focus of this study. The benefits of improved water quality were estimated using regression models that link turbidity and nutrients to water treatment costs at Durban Heights and Wiggins WTWs. Changes in sanitation and land use within the uMngeni catchment influences the amount of sediment, phosphorous and nitrogen entering river systems and water supply dams. Using hydrological modelling, sediment and nutrient export output can be established for the catchments within the EMA. These values can then be used to determine water treatment cost savings with changes in catchment land use by applying the water treatment cost model and values established for sediment and nutrient loads.

The water treatment cost generalised linear models were analysed by entering all variables into an ordinary least squares (OLS) regressoion using R Project for Statistical Computing (ver. 3.2.0). All costs were inflated to 2015 Rands. Collinearity was a concern with this model due to the large number of water quality variables that are related to one another. As a result a number of stepwise collinearity methods were used for determining which variables to retain and which to remove from the model. For example, iron was highly correlated with turbidity, suspended solids, E.coli and total organic carbon (TOC). Suspended solids and turbidity were also highly correlated. In order to link sediment loads (kg) to water treatment costs it was more practical to include suspended solids in the model which is measured in mg/L rather than turbidity which is measured in Nephelometric Turbidity Units (NTU). A number of algal genera were included in the model, rather than just the total algal count. Stepwise regression methods were used to eliminate variables that were not contributing to the overall fit of the model. Month was included in the model to capture seasonal trends in water treatment costs.

A separate set of models were developed in order to relate the phosphorous loads entering the water supply dams to water treatment costs. Higher phosphorous levels in the uMngeni River entering Nagle and Inanda Dams were expected to be related to increased water treatment costs as a result of increased algal activity. This model was used to link changes in catchment land use to changes in nutrients entering water supply dams and the subsequent decrease in water treatment costs. Treatment costs (Rands per Mega-litre) were related to phosphorous loads in the river and other water quality variables such as coliforms and water colour. Because phosphorous loads were highly correlated with TSS, turbidity, iron, nitrogen, pH and E.coli they were removed from the model through AIC stepwise analysis.

A5.5 Results

A5.5.1 Durban Heights WTW

The total water treatment costs at Durban Heights WTW in terms of chemical cost composition were similar to those described by Graham (2004). Caogulant (and flocculation) costs and disinfection costs contributed the most to the overall treatment costs with coagulant costs contributing 41.4% and disinfection costs 42.9% (Figure A5. 2). The coagulant and disinfection processes during water treatment remove unwanted sediments, algae, odours and colour from the raw water.

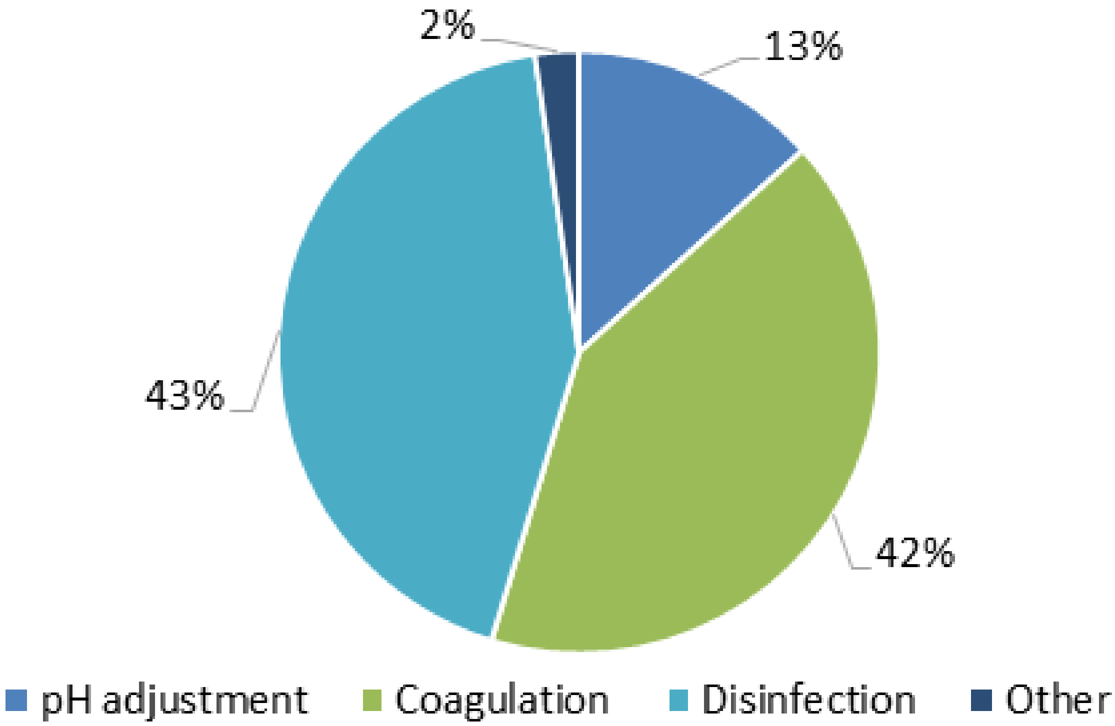

Figure A5.2 Average treatment cost breakdown at Durban Heights WTW.

Treatment costs increased steadily between 2010 and 2015 (Figure A5. 3), with clear seasonal fluctuations. Treatment costs were higher over the summer months from November through to March when rainfall is at its highest in the EMA.

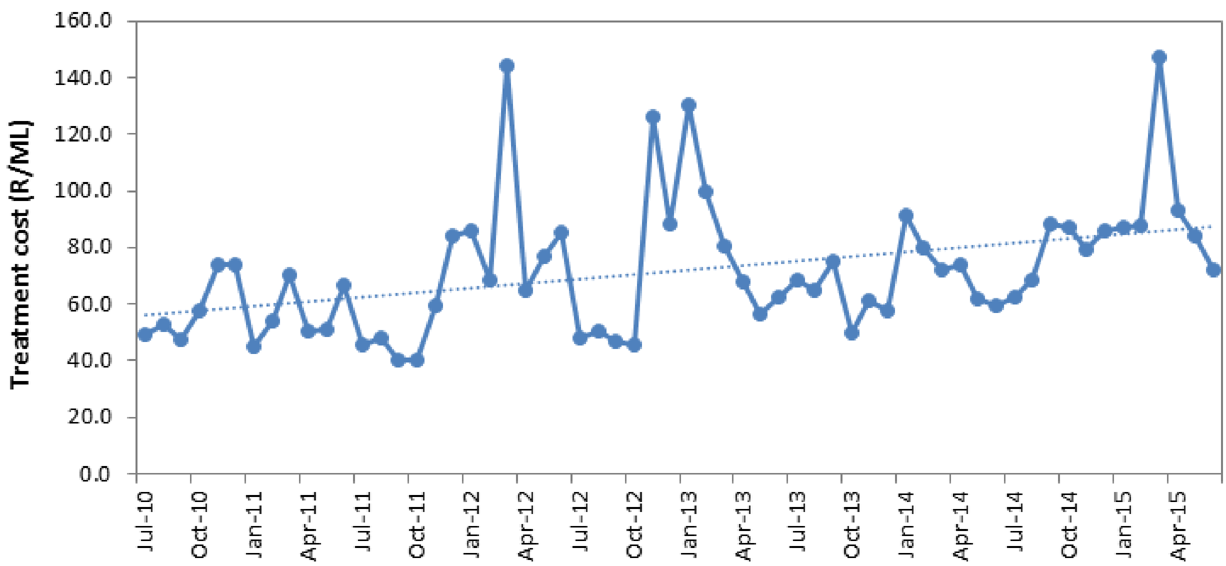

Figure A5.3 Total water treatment costs for Durban Heights WTW from July 2010 – June 2015

Figure A5. 3. Total water treatment costs for Durban Heights WTW from July 2010 – June 2015

The regression estimates for the water treatment model where treatment cost (R/ML) is the dependent variable and a number of water quality parameters are the independent variables is shown in Table A5. 4. The model was highly significant with an R-squared of 0.922, representing a strong relationship between actual and predicted treatment costs (Figure A5.4).

Table A5.4 Estimated coefficients of variables affecting water treatment costs at Durban Heights WTW

	Coefficient	Std. Error	t.value	Pr(>|t|)	
Intercept	-109.0000	103.2000	-1.0560	0.2990	
Suspended Solids	0.9473	0.2600	3.6430	0.0010	***
pH	21.2400	13.1200	1.6180	0.1157	
Coliforms	0.0049	0.0016	2.9860	0.0055	**
Anabaena	0.0172	0.0059	2.8970	0.0068	**
Ceratium	0.2282	0.1235	1.8470	0.0742	.
Chlorella	0.5319	0.1270	4.1870	0.0002	***
Coelastrum	0.0173	0.0094	1.8420	0.0751	.
Crucigenia	-0.0903	0.0374	-2.4160	0.0218	*
Cyclotella	-0.0866	0.0257	-3.3700	0.0020	**
Dictyosphaerium	0.1690	0.0229	7.3780	0.0000	***
Scenedesmus	-0.1602	0.0380	-4.2190	0.0002	***
Quadrigula	0.0809	0.0282	2.8660	0.0074	**
Sphaerocystis	0.0142	0.0091	1.5680	0.1270	
Melosira	-0.0418	0.0173	-2.4130	0.0219	*
Month dummies				significant	
R-squared				0.9220	

Notes: (1) ***p<0.001, **p<0.01, *p<0.05, .p<0.10.

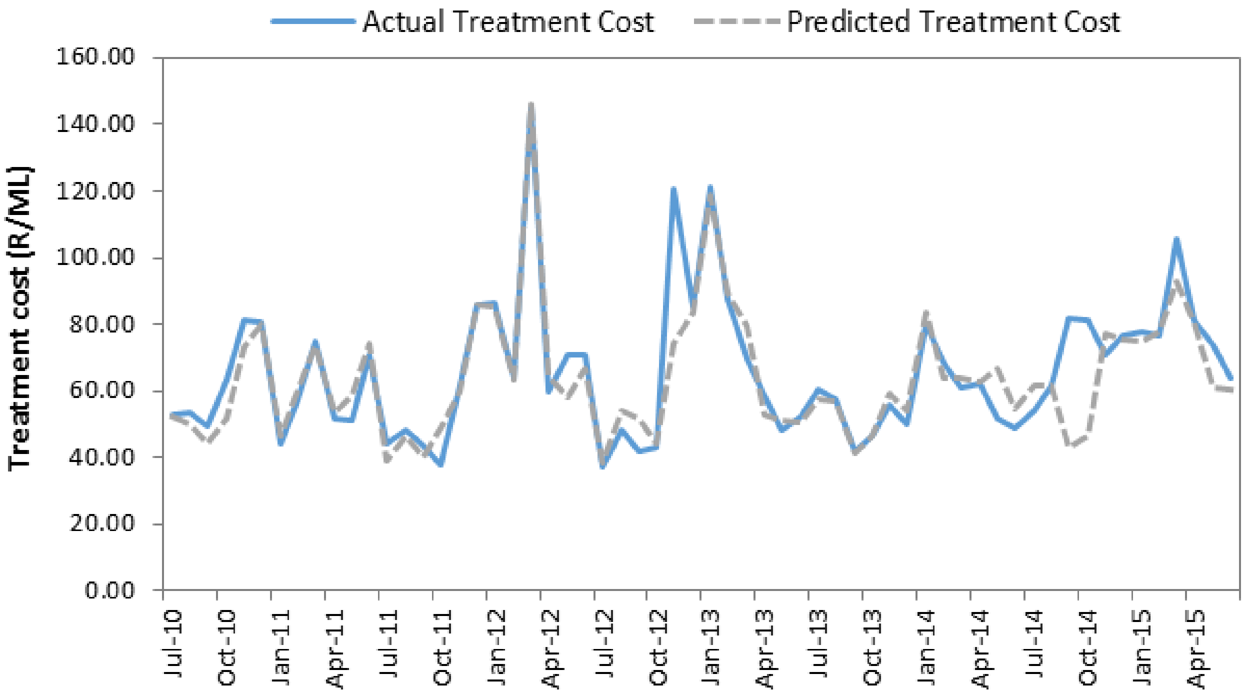

Figure A5.4 Actual versus predicted water treatment costs fitted using the treatment cost model estimates for Durban Heights WTW

Water treatment costs increased significantly in the summer months (November – March) as a result of increased rainfall and runoff resulting in increased suspended solids and algal blooms within the raw water being abstracted from Nagle Dam. Suspended solids have a significant impact on treatment costs, as do the level of coliforms in the water. High coliform counts are often associated with high rainfall events as a result of human and other wastes entering rivers and dams from urban, peri-ubran and rural settlement runoff. The rising costs associated with these factors are a result of increased usage of coagulants and disinfectants when coliform and suspended solid concentrations are high. A number of algae were found to significantly influence treatment costs, with some having a positive impact and others a negative impact on overall costs. Anabaena is a genus of filamentous cyanobacteria that can release harmful toxins and also cause taste and odour problems in water. Difficult and costly treatment methods are needed to remove tastes and odours from water, such as powdered activated carbon (Graham 2004). Algal levels tend to increase when nutrient levels rise, especially when phosphorous levels are high in the inflow water, and this is often during summer months when phosphorous levels increase due to high rainfall. These factors are all directly related to water pollution as a result of both anthropogenic inputs such as accelerated erosion and sewage, and natural inputs such as siltation. Runoff from agricultural activities such as cattle lots and from informal settlements increase nutrient levels in rivers and dams. Figure A5. 5 shows the general trend of increasing phosphorous and nitrogen loads entering Nagle Dam and the seasonal peaks in nutrient concentrations over a five year period (data taken from the sampling station on the uMngeni River upstream of Nagle Dam).

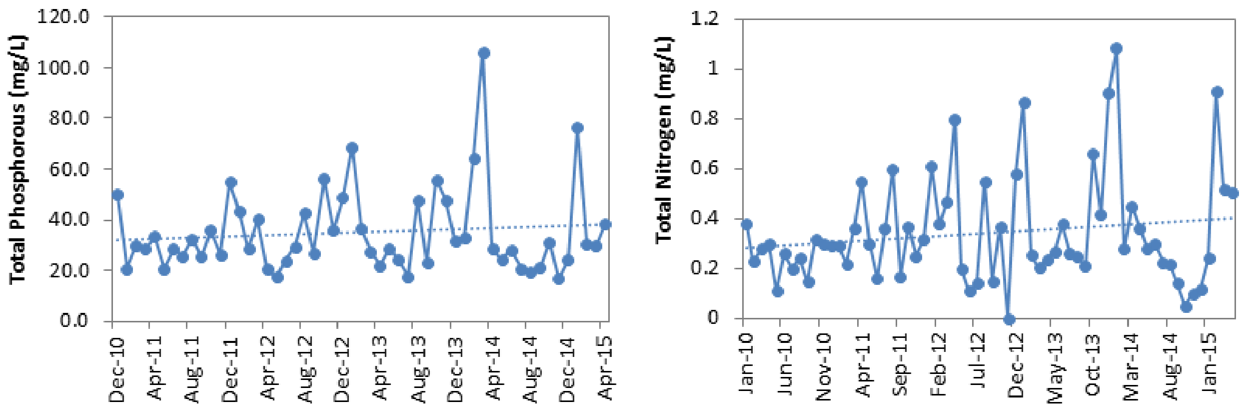

Figure A5.5 (a) Total phosphorous concentrations (mg/L) Dec 2010 – April 2015 and (b) Total nitrogen concentrations (mg/L) Jan 2010 – April 2015 at the inflow to Nagle Dam on the uMngeni River

Phosphorous loads in the uMngeni River entering Nagle Dam were positively and significantly correlated with water treatment costs at Durban Heights WTW (Figure A5. 6, Table A5. 5). Phosphorous loads were strongly correlated with Turbidity, TSS, E.coli, Iron and pH levels in the raw water abstracted for treatment. Phosphorous loads (kilograms of TP) were the highest over the summer rainfall months from November through to March resulting in increased water treatment costs as a result of increased turbidity, algae and coliforms within Nagle Dam and the subsequent need for higher coagulant and disinfection chemical dosages at Durban Heights WTW.

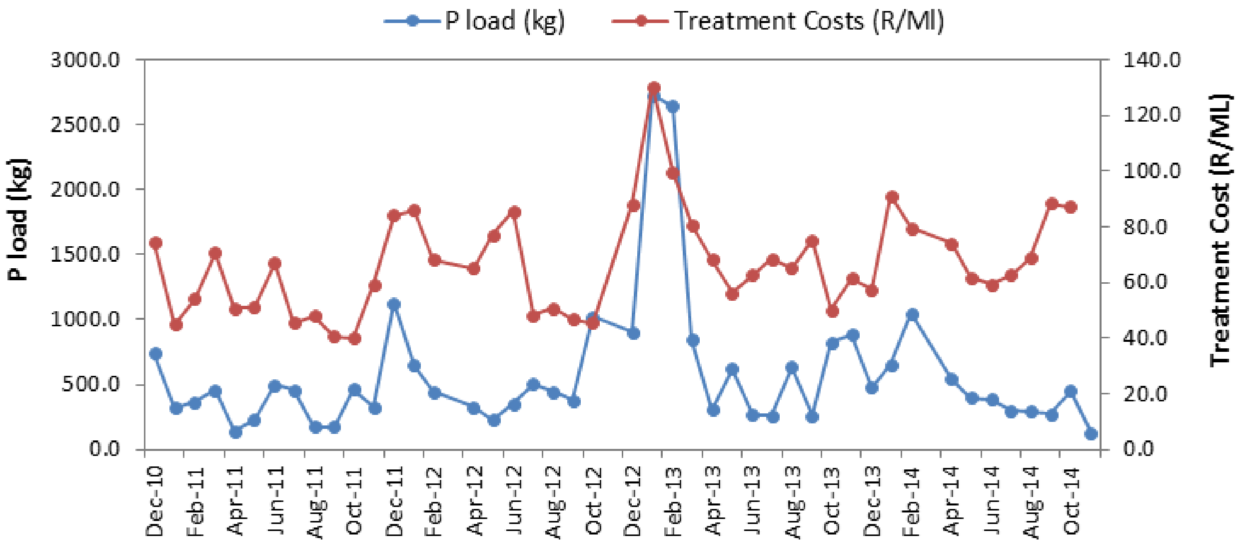

Figure A5.6 Average phosphorous loads (kg) in the uMngeni River above Nagle Dam and corresponding water treatment costs (R/ML) at Durban Heights WTW.

Table A5.5 Estimated coefficients of variables affecting water treatment costs at Durban Heights WTW

	Coefficient	Std. Error	t.value	Pr(>|t|)	
Intercept	47.780	23.007	2.077	0.045	*
Phosphorous Load	0.0152	0.0045	3.381	0.002	**
Temperature	0.6847	0.6740	1.016	0.316	
Coliforms	0.0056	0.0025	2.261	0.029	*
Colour	0.5012	0.4034	1.242	0.222	
Conductivity	0.9800	1.2397	-0.791	0.434	
R-squared				0.481	

Notes: (1) ***p<0.001, **p<0.01, *p<0.05, .p<0.10.

The model relating water treatment costs to phosphorous loads in the uMngeni River was significant with a reasonable fit to the actual treatment cost data provided for Durban Heights WTW (Table A5. 5, Figure A5. 7). The model relates changes in sanitation and land use within the uMngeni catchment to changes in water treatment costs. It is assumed that improved sanitation would decrease the phosphorous loads entering Nagle Dam, decreasing the frequency and magnitude of algal blooms, coliform numbers and TSS and therefore ultimately decreasing water treatment costs at Durban Heights WTW.

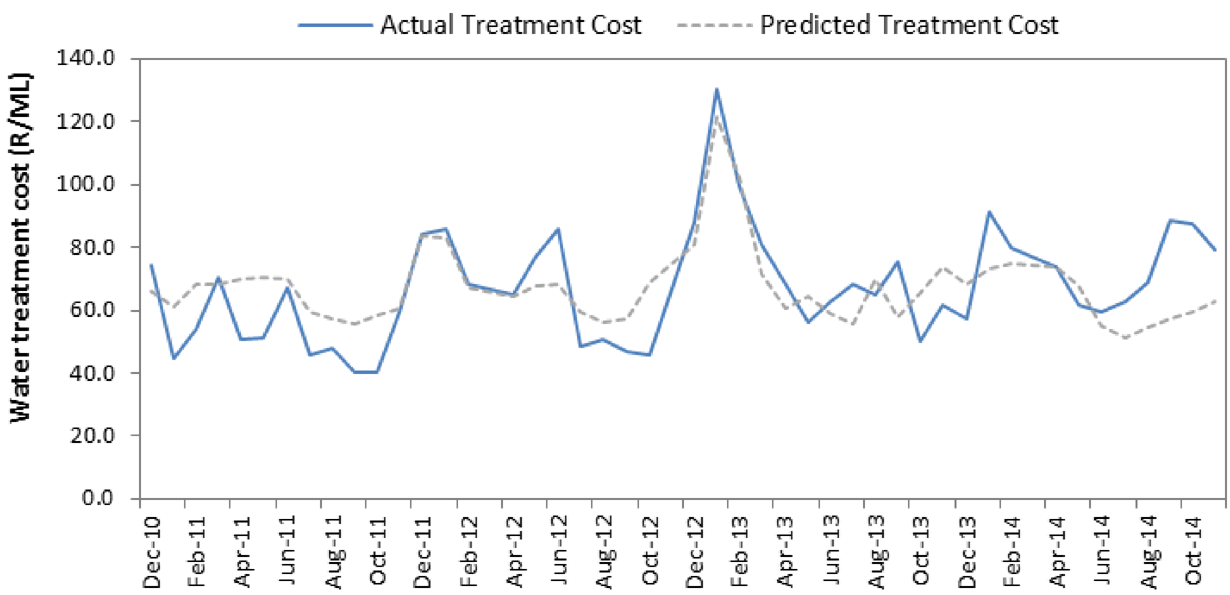

Figure A5.7 Actual versus predicted water treatment costs (R/ML) fitted using the treatment cost model estimates for Durban Heights WTW and the uMngeni River phosphorous loads.

A5.5.2 Wiggins WTW

The percentage breakdown of water treatment costs at Wiggins WTW are similar to those at Durban Heights WTW, with disinfection and coagulant costs making up 88% of total costs (Figure A5. 8). Water treatment costs increased between 2010 - 2015 (Figure A5. 9). On average water treatment costs are cheaper at Wiggins WTW than at Durban Heights WTW with a mean of R67 per ML compared to R72 per ML at Durban Heights. This is similar to the findings presented in Graham (2004). One explanation for this could be the size difference in the dams supplying the raw water to the treatment works. Inanda Dam is approximately ten times larger than Nagle Dam allowing for increased mixing and diluting of nutrients resulting in significant differences between the quality of water entering the dam and the quality of water being abstracted from outlet point for treatment. Rangeti (2014) noted that although Inanda Dam is considered badly polluted, the sheer size of the dam allows for dilution and mixing which improves the water quality before abstraction.

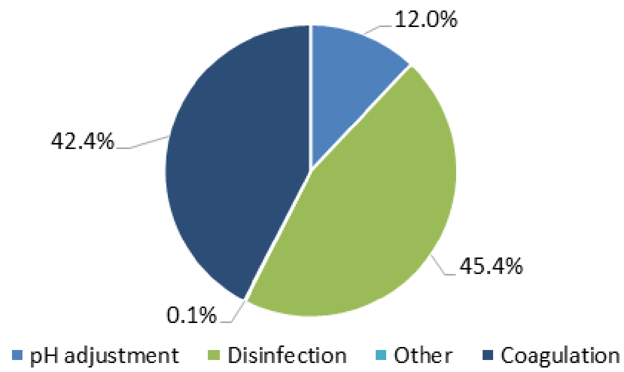

Figure A5.8 Percentage treatment cost breakdown at Wiggins WTW.

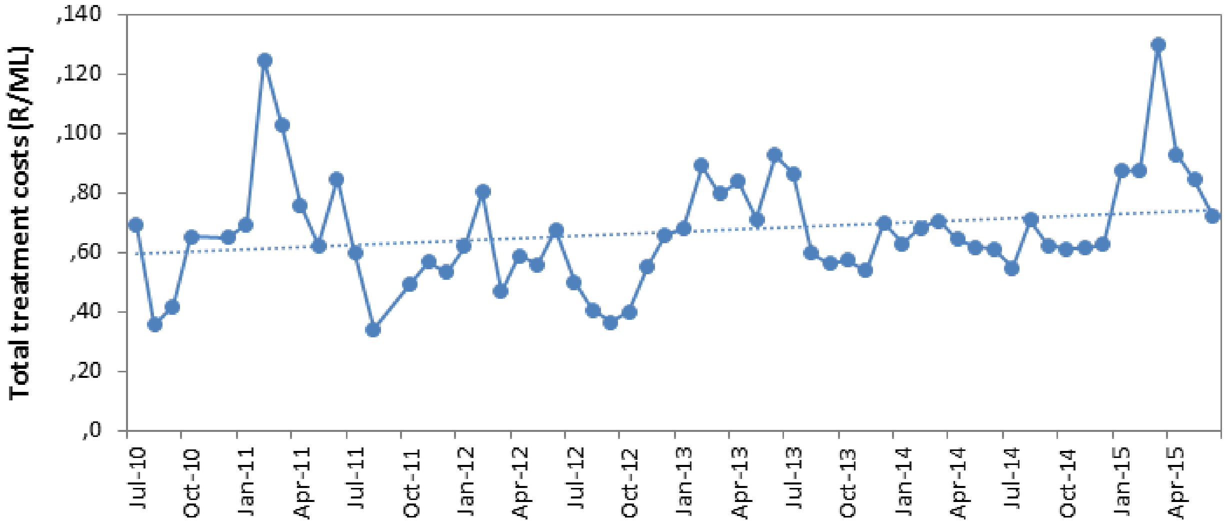

Figure A5.9 Total water treatment costs for Wiggins WTW from July 2010 – June 2015

The water treatment cost model results for Wiggins WTW are shown in Figure A5. 10 and Table A5. 6. The model was highly significant with Algae, Manganese, Alkalinity and the algal genera Anabaena having significant effects on water treatment costs. From the model it seems that algae has the largest influence on treatment costs at Wiggings WTW. Algal levels in Inanda Dam tend to increase during the summer rainfall months when nutrients entering waterways increase. Algae tend to increase filtration time and increase coagulation dosage during treatment (Rangeti 2014). Certain genera, such as the filamentous cyanobacteria, Anabaena, can have a significant impact on the taste and odour of the water being treated. When Anabaena cells are present in high numbers water treatment costs increase substantially.

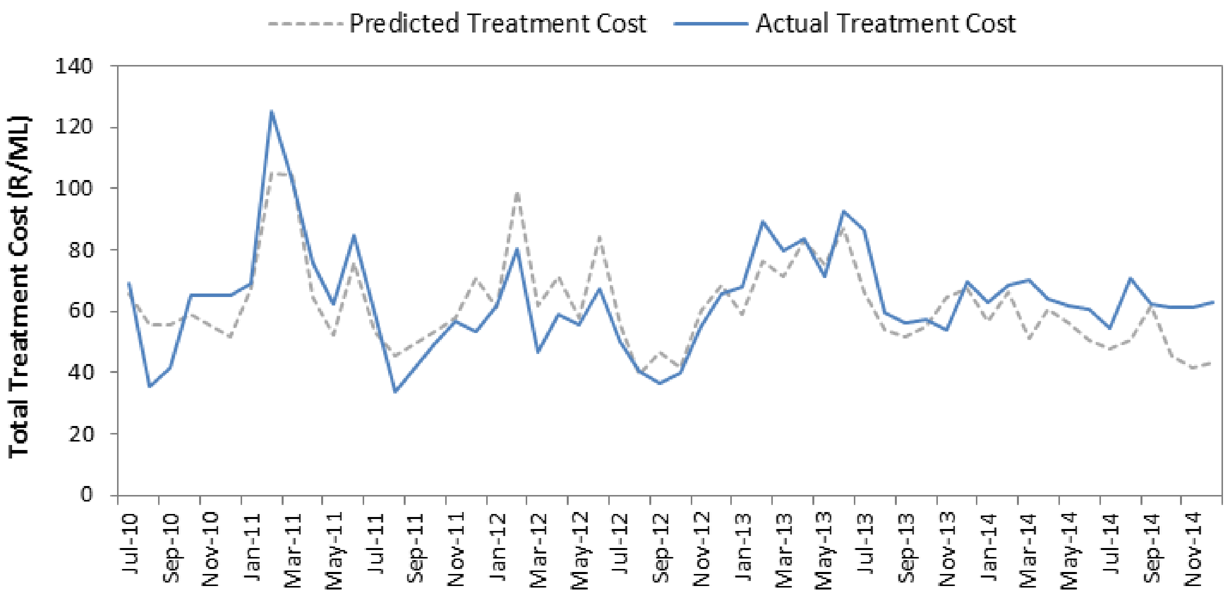

Figure A5.10 Actual versus predicted water treatment costs fitted using the treatment cost model estimates for Wiggins WTW

Table A5.6 Estimated coefficients of variables affecting water treatment costs at Wiggins WTW

	Coefficient	Std. Error	t.value	Pr(>|t|)	
Intercept	122.70	23.010	5.33	4.38e-06	***
Alkalinity	-1.33	0.390	-3.44	1.42e-03	**
Algae	0.004	0.001	7.70	2.37e-09	***
Manganese (Mn)	286.00	55.910	5.12	8.70e-06	***
Anabaena	0.047	0.020	2.09	4.32e-02	*
R-squared				0.682	

Notes: (1) ***p<0.001, **p<0.01, *p<0.05, .p<0.10.

Phosphorous concentrations in the uMngeni River above Inanda Dam have increased since 2010 (Figure A5. 11a). Phosphorous loads (kg of TP) were calculated using these concentrations and flow data from the same monitoring station. It was found that phosphorous loads at this site follow the same pattern as those found in the uMngeni River above Nagle Dam (Figure A5. 11b). However, the TP loads above Inanda Dam are significantly higher than those above Nagle Dam. It is expected that the higher phosphorous loads are a result of the Msunduzi River which joins the uMngeni River before this monitoring point. The Msunduzi River is known to be highly polluted. Although the phosphorous loads entering Inanda Dam are higher than those entering Nagle Dam, the size of Inanda Dam has a large dilution and settling influence on the water in the dam. Phosphorous loads entering Inanda Dam were found to have a significant impact on water treatment costs at Wiggins WTW (Figure A5. 12).

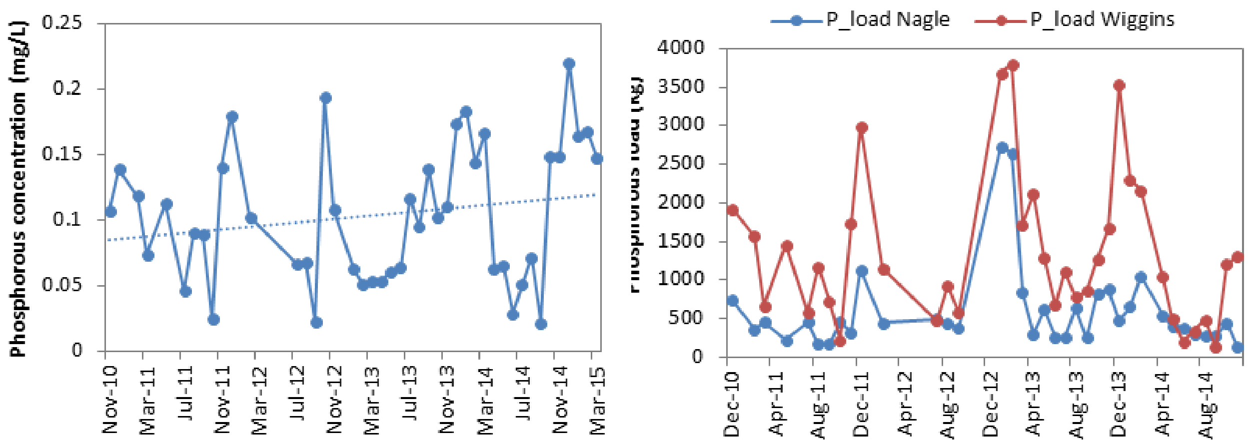

Figure A5.11 (a) Total phosphorous concentrations (mg/L) Dec 2010 – March 2015 in the uMngeni River above Inanda Dam, (b) Phosphorous loads (kg) in the uMngeni River above Nagle Dam and above Inanda Dam.

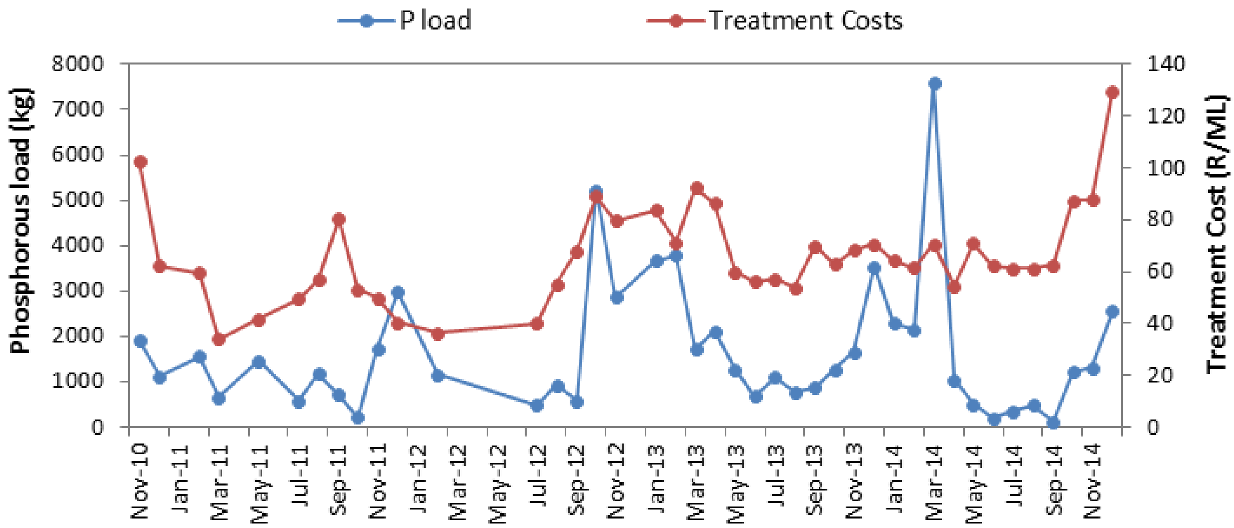

Figure A5.12 Average phosphorous load (kg) in the uMngeni River just above Inanda Dam and corresponding water treatment costs (R/ML) at Wiggins WTW (lag adjusted).

The model relating water treatment costs at Wiggins WTW to phosphorous loads in the uMngeni River was significant, although the fit of the model to the actual treatment cost data was not as strong as the model for Durban Heights WTW (Table A5. 7).

The reason for this can be explained once again by the size of Inanda Dam and the impact that dilution and mixing has on the incoming phosphorous loads as well as the direct correlation that phosphorous loads have with algae, TSS and temperature. Although the fit of the model is not strong, the relationship between treatment costs and phosphorous loads is significant. The analysis showed that there was a possible slight lag in phosphorous loads entering Inanda Dam and the treatment costs at Wiggins WTW. There are unknown variables within the system that would influence phosphorous levels such as temperature, wind, degree of dilution and mixing and the amount of phosphorous entering the system directly through runoff from rural settlements surrounding Inanda Dam. Understanding and capturing these complex interactions is difficult but from the analysis it is clear that phosphorous loads in the uMngeni River do have a significant influence on water treatment costs.

Table A5.7 Estimated coefficients of the water treatment cost - phosphorous load model for Wiggins WTW

<table>
<tr><th></th><th>Coefficient</th><th>Std. Error</th><th>t.value</th><th colspan="2">Pr(>|t|)</th></tr>
<tr><td>Intercept</td><td>135.10</td><td>37.38</td><td>3.615</td><td>0.0009</td><td>***</td></tr>
<tr><td>Phosphorous load</td><td>0.0049</td><td>0.002</td><td>2.807</td><td>0.0079</td><td>**</td></tr>
<tr><td>Alkalinity</td><td>-1.11</td><td>0.61</td><td>-1.813</td><td>0.0779</td><td></td></tr>
<tr><td>Manganese (Mn)</td><td>-334.70</td><td>1.04</td><td>-3.217</td><td>0.0026</td><td>**</td></tr>
<tr><td>R-squared</td><td></td><td></td><td></td><td>0.331</td><td></td></tr>
</table>

Notes: (1) ***p<0.001, **p<0.01, *p<0.05, .p<0.10.

A5.6 Conclusions

From this analysis it is clear that water quality had a significant impact on the cost of treating water at each of the WTWs studied. The models developed for Durban Heights WTW and Wiggins WTW are useful tools that can be used to predict the impacts of changes in water quality on water treatment costs. Regression coefficients, estimated using ordinary least squares, quantified the independent effects of each of the water quality parameters, such as phosphorous, as significantly effecting water treatment costs. These models can therefore be used to predict the outcome of catchment land-use changes, such as the impact that natural vegetation has on reducing nutrient runoff into surface waters. Using a simple scenario approach, comparisons between the status quo and modelled outputs can be related to the treatment costs and overall cost savings can be estimated.

APPENDIX 6: CONTRIBUTION OF GREEN OPEN SPACE TO PROPERTY VALUE

A6.1Introduction

It is well known that green open space and natural areas in cities provide a number of benefits, such as opportunities for recreation and tourism, attractive views, habitat for wildlife and other ecological benefits such as improved air quality and biodiversity conservation (Beron et al. 2001, Anderson & West 2006, Kong et al. 2007, Gibbons et al. 2011, Li et al. 2015). Open space may also be valued based on an absence of unpleasant qualities associated with development in cities, such as noise, traffic congestion and pollution (Irwin 2002, Anderson & West 2006, Kroeger 2008). As a result of rapid urbanisation in African cities and the subsequent increase in and sprawl of informal settlements, city managers and planners are constantly weighing up between developing and preserving open space areas. There is constant pressure to provide additional housing and to develop commercial and industrial areas further. However, the way in which residents value open space areas and the benefits that they provide in urban environments are often not well understood or are underestimated by urban planners resulting in poor zoning and land-use policy decision making and the ensuing loss of green open space (Anderson & West 2006, Behrer 2010).

The value that residents place on open space is reflected, to an extent, in private property and real estate markets (Kroeger 2008). When prospective homebuyers purchase a home they reveal certain preferences for different characteristics of the property through the amount that they are willing to pay for it (Taylor 2003, Behrer 2010). Homes that have a higher number of desirable characteristics are usually sold for a higher price when compared to homes with fewer of these characteristics. Housing attributes include physical characteristics of the property such as size of the living area, number of bathrooms, security, and condition of the property, neighbourhood characteristics such as schools and crime levels, and environmental characteristics such as scenic views and the amount of green open space surrounding a property. If residents do value open space and associated amenities then it would be expected that these values should be revealed in property prices. Property values associated with open spaces are therefore expected to vary according to factors such as the size of the open space, its distance from property, the type of vegetation cover and its overall appeal (Kong et al. 2007, Kroeger 2008). Household income is also considered to be an important variable (Kroeger, 2008), and this is especially relevant in the eThekwini Municipality in Durban where annual income varies significantly amongst households and across suburbs. In general it is expected that the proximity to well-maintained open space and views of natural areas lead to increases in surrounding property prices, which ultimately manifests in greater property tax revenues for municipalities.

The policy implications of understanding and quantifying the economic value of green open space can be beneficial to municipalities and urban planners (Anderson & West 2006, Behrer 2010). The benefits associated with environmental amenity are often underestimated by policy makers and urban planners (Kong et al. 2007, Lee et al. 2015) which has resulted in urban sprawl and the subsequent degradation and loss of green open spaces (Leiva & Page 2000, Kong et al. 2007). Local municipalities receive a significant portion of their revenue from property taxes and therefore have an incentive to maximise the value of properties within their jurisdiction. If policy makers are provided with information about how open space influences property sales and how their residents value open space areas, more informed decisions can be made in terms of land use planning and future development.

Literature looking at the effects of open space on residential property values is large and growing. McConnell & Walls (2005) conducted a broad review of studies that have valued the effects of open space on property markets and found that although the results tended to be case specific, they were able to conclude information about the direction of certain effects and how values vary by location. Other reviews include Banzhaf & Jawahar (2005) who focused on undeveloped land on the outskirts of cities and Kroeger (2008) who developed an open space property value tool through a comprehensive review of open space valuation studies. Numerous studies have estimated the amenity value of particular types of open space such as golf courses, neighbourhood parks, wetlands, forests and agricultural lands (e.g. Do & Grudnitski 1995, Doss & Taff 1996, Mahan et al. 2000, Tyrvainen & Miettinen 2000, Owusu-Edusei & Espey 2003, Nicholls & Crompton 2007, Gibbons et al. 2011), whilst others have focused on a spatial context of open space and estimated the effects of proximity, density and quality of open space on property values using land cover data and spatial analysis (e.g. Smith et al. 2002, Anderson & West 2006, Cho et al. 2006, Kong et al. 2007, Long et al. 2007, Cho et al. 2008, Behrer 2010, Jensen et al. 2014, Li et al. 2015). Anderson & West (2006) found, as expected, that the value of proximity to open space in the Minneapolis - St. Paul metropolitan area was higher in dense, high-income areas that were close to the Central Business District (CBD) and were home to many children. Surprisingly, the study found that residents in high-crime areas also placed a higher value on proximity to open space areas suggesting parks buffer against the negative effects of crime (Anderson & West 2006). A study conducted in Jinan City, China found that the size-distance index of forest, the accessibility to green parks and plazas, and the percentage of green urban space were all significant and confirmed the positive amenity impact of proximate green space on property prices (Kong et al. 2007). Troy & Grove (2008) found that park proximity is positively valued by the housing market in Baltimore City, Maryland where the combined robbery and rape rates for a neighbourhood were below a certain threshold rate but negatively valued when above that threshold. Gibbons et al. (2011) estimated the amenity value of nature on property prices in the United Kingdom and found that gardens, green space and areas of water all attract a considerable positive price premium. They also found that increasing distance to natural amenities such as rivers and national parks is associated with a decrease in property prices.

In Durban it is expected that the socio-economic variables such as household income and population density could have a significant influence on property values and the amenity value associated with open space. One would expect that people with higher incomes are more willing to pay for open space or scenic views when compared to people with very little disposable income. People living in denser areas may place a higher value on open space and the recreational opportunities that they provide, such as open space for practicing football, however those living in dense surroundings usually form part of the lower income group in the population with their willingness to pay for open space often not reflected in property prices.

This study aims to determine the contribution of green open space to residential property value in the EMA. Using a hedonic analysis of property sales data from the EMA we estimate the effects on property value of a number of different types of open space; proximity to the coastline, neighbourhood parks and the amount of natural open space surrounding each property (e.g. rivers, forests, grassland and woodland). The condition of each natural open space patch was also taken into consideration and forms an important part of the study. Geographic Information Systems (GIS) was used to determine spatial variable estimates. The effects of population density, amenity size, household income and other covariates believed to influence the value of open space were also included in the analysis.

A6.2Methods

A6.2.1 The econometric model

Property value associated with environmental assets is generally estimated using the Hedonic Pricing Method (HPM), a form of multiple regression analysis. The HPM assumes that the final price of a good is a function of the values of the individual attributes (Rosen 1974). Therefore the method is used to measure the implicit value of a property's underlying characteristics (i.e. structural, locational and environmental; Gibbons et al. 2011). A HPM relates the market price of a property to these attributes, with each property owner choosing their property based on utility maximization given by the price function (Taylor 2003, Anderson & West 2006). Using standard hedonic theory (Rosen 1974) each property in this study was defined by its structural, neighbourhood and environmental characteristics and the general hedonic price function was applied:

$$P_p = f(x_s, x_n, x_e)$$

where P_p is the sales price of the property and x_s,x_n,x_e are the structural, neighbourhood and environmental characteristics related to P_p.

Beyond the structure of the model there is a need to determine which functional form to use, something that is not specified in the economic theory surrounding hedonic price equations (Rosen 1974, McConnell & Walls 2005, Kong et al. 2007, Behrer 2010, Gibbons et al. 2011). There are a number of functional forms that can be used for the regression analysis, such as linear, semi-log, log-log and quadratic forms (see Taylor 2003). The standard in more recent studies (Cho et al. 2008, Troy & Grove 2008, Poudyal et al. 2009, Conway et al. 2010, Gibbons et al. 2011, Li et al. 2015) has been to use the semi-log regression model where the dependent variable is the natural logarithm of the sale price for each property. This is the functional form applied to the model used in this study. This approach allows the coefficients of a semi-log model to be interpreted as a percentage change in prices (Kong et al. 2007, Gibbons et al. 2011).

In this study, the semi-log model was specified by a natural log transformation of the housing sales price in the hedonic regression. The model applied is as follows:

$$Ln\, P_{pt} = \beta_0 + \beta_1 S_{pt} + \beta_2 N_{pt} + \beta_3 E_{pt} + \varepsilon_{pt}$$

where the dependent variable ($L_n\, P_{pt}$) is the natural logarithm of the sale price for each property transaction 'p' in period 't'. S_{pt} represents the structural housing characteristics, N_{pt} the measure of neighbourhood characteristics and E_pt represents the environmental variables of interest. Similarly β_0,β_1,β_2,β_3 represent the corresponding parameters to be estimated, whereas ε_{pt} captures the stochastic error term.

A total of 44 variables were chosen in the construction of the hedonic regression. See Table A6. 1 for descriptions of these variables. The modelling procedure involved entering all variables into an ordinary least squares (OLS) regression using R Project for Statistical Computing (ver. 3.2.0). Presence of multicollinearity was tested using the Variance Inflation Factor (VIF). The VIF specifies the strength of linear dependencies and identifies how much of the variance of each coefficient is inflated due to collinearity when compared to the independent variables which are not linearly related (Cho et al. 2008, Poudyal et al. 2009, Yoo et al. 2014). There is no formal rule associated with VIF scores (Yoo et al. 2014). The generally accepted approach is that multicollinearity is not an issue when the VIF is less than 10 (Cho et al. 2006, Cho et al. 2008, Poudyal et al. 2009, Treg 2010, Yoo et al. 2014). However, other studies have applied a VIF of less than 5 (Anderson 2000; Troy & Grove 2008) and this was the threshold applied during this study. A score of 1 denotes perfectly correlated variables (Troy & Grove 2008).

Certain variables, such as the number of bathrooms, were found to be insignificant as well as correlated with other variables in the model and were therefore removed from the specification. To test for clustered error terms within the robust standard error OLS baseline model, a cluster robust estimator was implemented to account for cluster-error at the suburb level. If the errors of the baseline model are in fact clustered then the cluster-adjusted model helps to improve standard error estimates. Incorrect standard errors can lead to incorrect t-statistics and p-values. If the errors are not clustered then the cluster-adjusted model yields the same standard error estimates as if the cluster had not been specified. The results from the two additional cluster-adjusted models that were implemented were the same as the baseline OLS model suggesting that clustering concerns at the suburb level are not warranted.

Previous studies have found that a log transformation of distance variables, monetary value variables and area variables generally perform better than a linear functional form because the log transformation captures the declining effect of these variables (Taylor 2003, Bin & Polasky 2004, Cho et al. 2008, Poudyal et al. 2009, Li et al. 2015). For example, the price effect of moving one distance unit closer to the coastline should decrease as distance to the coastline increases; i.e. a move from 50m to 200m from the coastline is expected to have a large impact on property price, while a move from 2000m to 2150m from the coastline is expected to have only a negligible effect on price. The log transformation also corrects for heteroscedasticity in the dataset (Wooldridge 2003). Therefore, a natural log transformation was applied to the distance, household income, and area-related variables.

A6.2.2 Property and locational data

Table A6. 1 lists the variables used to estimate the property analysis model equation and Table A6. 2 provides a summary of descriptive statistics for our sample data. Our units of analysis for this study are individual residential properties located across the eThekwini Municipal Area. Property sales data from January 2012 to October 2014 provided by the eThekwini Municipality Real Estate Department were analysed. The data set contained details on 17,476 residential free standing properties within the EMA, including details about location, type, size, condition, number of bathrooms, and the presence/absence of a garage and swimming pool. Approximately 8% of the observations were omitted from the analysis because of missing or implausible data, reducing the sample size to 16,149 property transactions.

Each property sale transaction in the dataset had a unique PIN which allowed for matching each sale with a property boundary (erf) in the GIS eThekwini cadastral layer. Figure A6. 1 shows the location of all 16,149 properties included in the sample set and indicates if their sales price was above or below the study sample mean of R998 302.

The dependent variable in the model is the natural logarithm of the sales price for each residential property. The date at which each property was sold was included as a dummy variable in the model by grouping the sale of the property annually (2012, 2013, and 2014). Structural housing characteristics include property size in the form of Total Living Area (TLA, m2), and a number of dummy variables; garage (yes, no), swimming pool (yes, no), level of security (medium-high, none-low), type of view (sea, partial sea, panoramic, surrounds, commercial, industrial, informal settlement), and condition of the property (good, average, poor). These variables were measured by the eThekwini Real Estate Department as part of the housing assessment process. The level of security is based on how secure the property is in terms of safety structures such as security gates, alarm systems and boundary walls. The view from the property is based on the main setting or visual from the front of each property.

The data used for the neighbourhood variables came from a number of sources. The distance to CBD attribute was calculated using GIS and land use layers provided by the eThekwini Municipality and was based on the distance to the Durban CBD from each individual property. Schools are an important local public service and it is expected that housing prices are effected by the location and quality of schools within an area. For this analysis only distance to the nearest independent (or private) primary and secondary schools were included. Distance to the nearest school was estimated for each property using GIS locational data for schools as provided by the municipal GIS department. Population density and household income variables were estimated using Census 2011 data provided by StatsSA. Census data was available for every sub-place (i.e. suburb) across the EMA allowing us to estimate population density and modal household income per census sub-place.

A6.2.3 Land cover data

GIS was used to calculate the environmental and neighbourhood spatial variables used in the model. A land use land cover (LULC) map produced by the eThekwini GIS Department was combined with the Durban Metropolitan Open Space System (D'MOSS) map produced by the eThekwini Environmental Planning and Climate Protection Department which considers the condition of each natural green open space parcel in the municipal area. In order to account for potentially important areas that are more distant than within immediate proximity to a property, the total quantity of open space surrounding each property was measured within three given buffer distances. Once the single land use map was created the spatial variables were calculated using buffer analysis in GIS by calculating the total quantity of different types of open space within three different sized buffer areas; an immediate buffer with a 300m radius surrounding each property, a neighbourhood buffer with a radius of 1500m surrounding each property and a more regional buffer with a 5000m radius surrounding each property. In doing so the effect of distance and locality of open space on property prices could be determined. The buffers surrounding each property were exclusive of each other in that the amount of open space within the smaller 300m buffer was not included in the larger 1500m buffer and so on. In doing so the buffers remained independent of one another and the impacts of collinearity were significantly reduced.

Industrial areas, commercial areas and main roads are assumed to have an influence on property prices and these variables were included in the analysis as the total amount of major road network, industrial and commercial land surrounding each property within each of the three buffers.

Different types of green open space may influence housing prices in a number of different ways and this was considered when developing the model. Recreational open space such as a golf course may have a very different influence on property price when compared to natural vegetated areas. As such, the model developed for this study included a number of different types of open space. Two types of urban green open space were considered in the model; (1) golf courses and (2) park land. With regards to local environmental characteristics, five broad habitat categories were used based on the D'MOSS and the land cover map: (1) Forest; (2) Estuaries and rivers; (3) Grasslands; (4) Broad-leaved/ mixed woodland and thicket; and (5) enclosed sugarcane farmland. These were further grouped together into (1) Natural Vegetated Areas (forest, grassland, mixed woodland); (2) Natural Aquatic Areas (estuaries and rivers); and (3) Farmland. For each property, the total amount of each type of open space was determined within the 300m, 1500m and 5000m buffer radius. For rivers, the length of river located within each buffer was used. In addition to these natural amenities, the distance to coastline from each property was also included. Distance was measured as the straight line distance in kilometres to the nearest edge of coastline from the property. The "greenness" of each sub-place was determined by estimating the percentage tree cover in each residential neighbourhood by overlaying the census sub-place layer in Google Earth. Within each sub-place five stretches of residential roadway inside of each residential area were randomly selected and the percentage tree canopy cover along the verge of each of the five selected roads was determined. The overall percentage tree cover for each sub-place was based on an average of these five estimates.

The condition of the natural open space was also considered as it is assumed that degraded patches of natural vegetation may influence property price differently to patches in a good condition. Three condition levels were used (good, intermediate, degraded) to determine if condition does in fact affect amenity value. The condition data were provided by the eThekwini Environmental Planning and Climate Protection Department based on their assessment of the ecological condition of natural open space systems in the EMA. These condition factors were applied to all natural vegetated and aquatic environments within the EMA. The condition of the rivers and estuaries in the EMA was based on water quality data provided by the eThekwini Department of Water and Sanitation and included over 100 sampling stations. The water quality data from each station was used to allocate a "fitness for use" condition (based on E.coli counts and total permanganate levels) to each stretch of river as recommended by the Department of Water and Sanitation (DWS) guidelines.

With our analysis come certain limitations. It is very difficult to control for all relevant local scale characteristics because we do not have sufficient data on all variables, such as data on local crime levels, local air quality and the extent or type of domestic gardens and their influence on "greening" neighbourhoods. Including all possible variables in the regression analysis becomes impractical even with access to all data and therefore we rely on the set of control variables, such as population density, household income and the amount of industrial and major road networks described above which would be correlated to other relevant neighbourhood characteristics that are not included in our model, such as pollution or noise levels.

Table A6.1 Definitions of variables used in the model

Variable name	Definition
Structural variables	
Sales Price	Property transaction price (Rands)
Date	Year of sale: 2012, 2013, 2014
Total Living Area	Total area of main living space (m2)
Garage	Presence/absence of a garage
Pool	Presence/absence of a swimming pool
Security	Level of security: Med-high or None-low.
View	View from property: Sea, Partial Sea, Panoramic, Surrounds, Commercial, Industrial, Informal Settlements
Condition	Condition of property: Good, Average, Poor
Neighbourhood variables:	
Population density	Number of persons per km2 in census sub-place
CBD	Distance to Central Business District (km)
School	Distance to nearest independent school (m)
Income	Modal household income per census sub-place (Rands)
Industry	Amount of industrial land within property radius (ha)
Commercial/Retail	Amount of commercial/retail land within property radius (ha)
Road	Amount of major roadway within property radius (ha)
Coastline	Distance to nearest coastline point (km)
Tree cover	Percentage neighbourhood tree cover per census sub-place (%)
Open space amenities:	
Golf course	Amount of golf course within property radius (ha)
Park	Amount of park land within property radius (ha)
Sugarcane farmland	Amount of sugarcane farmland within property radius (ha)
Natural vegetation	Amount of natural vegetated open space in a good (1), intermediate (2) or degraded (3) condition within property radius (ha)
Rivers	Length of river in a good (1), intermediate (2) or degraded (3) condition within property radius (m)

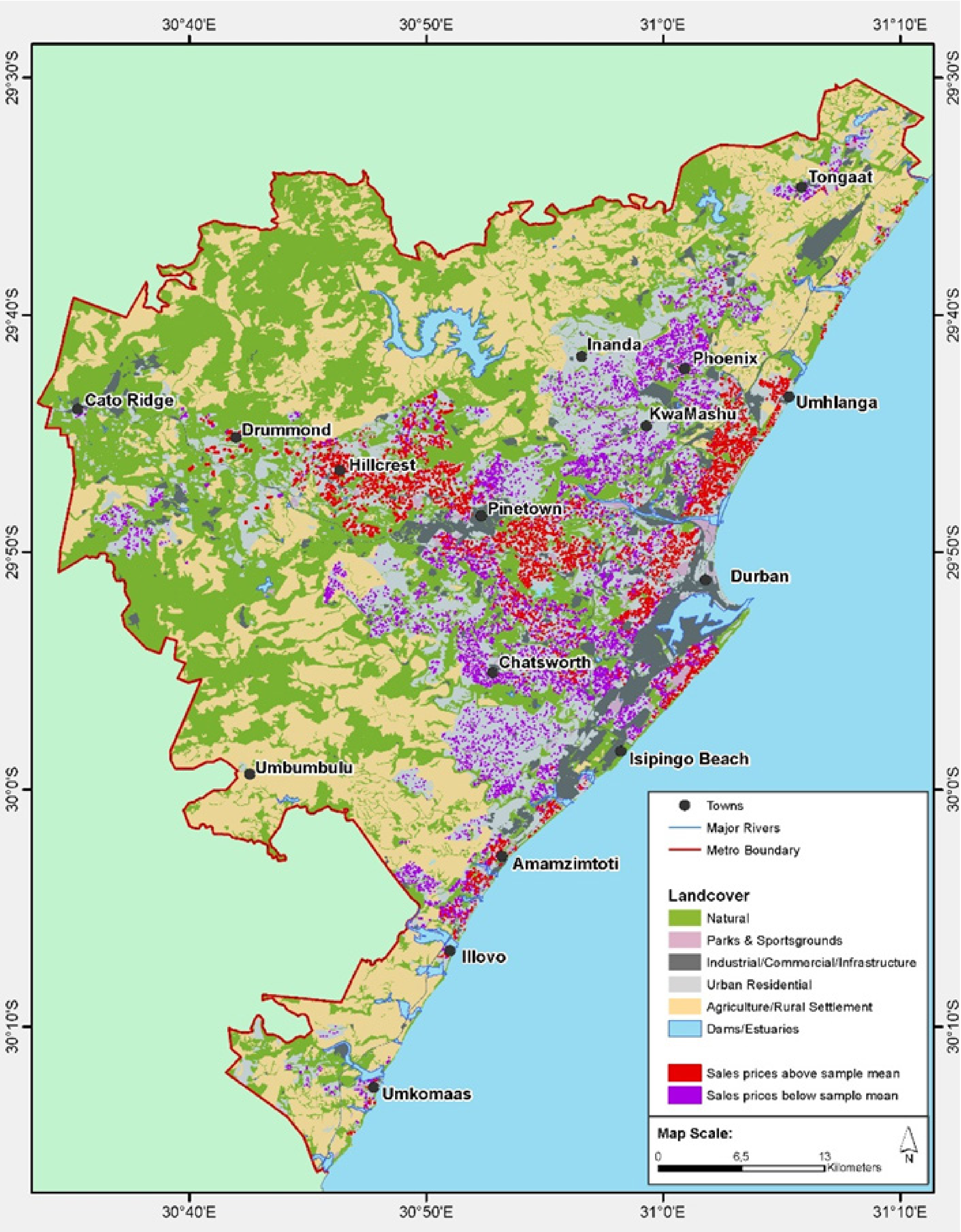

Figure A6.1 Location and values of properties in the EMA. Figure is based on the sample size of 16149 property sales from January 2012 – September 2014. Red indicates properties that exceed the sample mean value of R998 302 and the purple indicates properties with sales prices below the study sample mean.

Table A6.2 Summary statistics based on estimation sample of 16149 properties in the EMA between January 2012 and October 2014. (1), (2) and (3) adjacent to natural vegetation and rivers indicate the condition where (1) is good, (2) is intermediate and (3) is degraded.

Variables	Mean	Std Dev	Min	Max
Property Price (Rands)	998,302	1,037,171	30,000	16,000,000
Total Living area (m2)	131.79	79.97	10.00	918.00
Distance to CBD (km)	14.68	8.06	0.64	47.27
Population Density (ppl/km2)	3867.89	3130.25	21.12	26214.57
Modal HH Income	136,497	111,748	7,200	921,400
Distance to nearest school (m)	2645.86	2098.98	18.35	15148.38
Distance to nearest coastline (km)	9.69	7.72	0.06	44.6
Tree Cover (%)	30	22	0	80
Within 300m radius:				
Natural vegetation (1) (ha)	0.88	2.51	0.00	27.42
Natural vegetation (2) (ha)	0.87	2.14	0.00	27.51
Natural vegetation (3) (ha)	0.94	2.14	0.00	27.33
Main rivers (1) (m)	25.30	120.81	0.00	1342.78
Main rivers (2) (m)	57.89	193.58	0.00	1630.64
Main rivers (3) (m)	1.94	32.26	0.00	1195.34
Golf (ha)	0.12	0.99	0.00	18.40
Park (ha)	0.39	1.30	0.00	17.39
Sugarcane farmland (ha)	0.12	1.00	0.00	21.02
Commercial/Retail (ha)	0.21	0.94	0.00	18.61
Industry (ha)	0.34	1.47	0.00	21.59
Roads (ha)	0.25	0.71	0.00	10.74
Within 1500m radius:				
Natural vegetation (1) (ha)	35.47	46.26	0.00	426.39
Natural vegetation (2) (ha)	30.26	30.96	0.00	214.44
Natural vegetation (3) (ha)	29.99	32.51	0.00	305.73
Main rivers (1) (m)	814.41	1456.22	0.00	8537.70
Main rivers (2) (m)	1835.22	2153.05	0.00	11895.11
Main rivers (3) (m)	99.24	474.33	0.00	4430.78
Golf (ha)	3.50	12.41	0.00	111.83
Park (ha)	8.29	13.09	0.00	87.81
Sugarcane farmland (ha)	11.41	41.27	0.00	414.97
Commercial/Retail (ha)	9.44	15.41	0.00	146.59
Industry (ha)	26.67	44.10	0.00	301.23
Roads (ha)	8.05	10.06	0.00	72.14

Variables	Mean	Std Dev	Min	Max
Within 5000m radius:				
Golf (ha)	29.30	42.47	0.00	180.73
Park (ha)	55.95	55.25	0.00	248.01
Sugarcane farmland (ha)	215.30	510.74	0.00	3396.17
Commercial/Retail (ha)	101.26	99.61	0.00	540.64
Industry (ha)	395.69	332.97	0.04	1423.34
Roads (ha)	88.77	73.89	0.00	335.86

A6.2.4 Assigning values to green open space areas

In order to assign a value to green open space it was necessary to calculate the premium associated with natural open space and park land, aggregate the model results, and determine spatially the value associated with each patch of green open space. Each property was assigned to a census level sub-place (roughly equivalent to a suburb) and the effect of open space (natural and parkland) on property values was obtained from the estimated model coefficients, which provide the percentage change in property value given a unit change in the value of the open space variable under consideration. The aggregate effect of open space in the EMA was then estimated by applying the regression results to the entire stock of residential houses with a property extent of less than 5000 m2 within each sub-place of the EMA. Sub-place units were found to be too small and as a result the total premiums per sub-place were combined into a slightly larger scale of census main-place level. Using GIS, the total amount of natural vegetation in a good condition and the amount of public park land was established for each sub-place and then for each main-place. The value (R/ha) associated with each area of open space or parkland could then be calculated based on total premiums and the total amount of green open space present within each main-place.

A6.3Results and discussion

A6.3.1 Model estimations

Table A6. 3Error! Reference source not found. presents the regression estimates from the hedonic property model. A White test of heteroscedasticity rejected the null hypothesis of homoscedasticity at the 1% level in the hedonic regression. White's heteroscedasticity-correlated covariance matrix was used to make inference and the results from the regression based on the updated standard error terms. Computed values of VIF did not exceed the threshold value of 5, with none of the variables being higher than 3. Conventional adjusted R2 (0.81) reveals a good fit of the data into the specified model. Coefficients on most of the variables were statistically significant at the 1% or better level and most of them had the expected signs.

Certain variables were dropped from the model if they did contribute to the overall fit. These variables were found to be insignificant and by removing them, the model fit improved and the VIF values improved for remaining variables. For example, distance to the CBD was unexpectedly found to have a positive influence on housing prices, was insignificant and was subsequently dropped from the model. This may be a result of the EMA having more than one central business district with areas like Westville, Pinetown and Umhlanga having important and relatively large business centres and industrial parks themselves making the centre of Durban less important as a CBD.

Table A6.3 Model estimation results

Variable	Co-efficient	Standard error	t-value	Pr(>|t|)	p
(Intercept)	7.21820	0.12430	58.07	< 2.2e-16	***
Ln(TLA)	0.59723	0.01038	57.54	< 2.2e-16	***
View Industrial	0.03184	0.05975	0.53	0.59416	
View Informal Settlement	-0.07022	0.06300	-1.11	0.26504	
View Panoramic	0.01284	0.05649	0.23	0.82018	
View Partial Sea	0.17231	0.05858	2.94	0.00327	**
View Sea	0.25139	0.07092	3.54	0.00039	***
View Surrounds	0.01480	0.05536	0.27	0.78927	
Security - Low/None	-0.09165	0.00821	-11.17	< 2.2e-16	***
Condition - Good	0.08011	0.00822	9.74	< 2.2e-16	***
Condition - Poor	-0.29831	0.01365	-21.86	< 2.2e-16	***
Garage - Yes	0.09924	0.00897	11.06	< 2.2e-16	***
Pool - Yes	0.07163	0.00827	8.67	< 2.2e-16	***
Density	-0.00001	0.00000	-4.28	0.00002	***
Ln(Income)	0.30389	0.00807	37.65	< 2.2e-16	***
Ln(DistanceSchool)	-0.03265	0.00540	-6.05	1.498E-09	***
Ln(DistanceCoast)	-0.02660	0.00415	-6.42	1.443E-10	***
Golf - 300m	0.02886	0.00489	5.90	3.695E-09	***
Park - 300m	0.01432	0.00283	5.07	4.065E-07	***
Road - 300m	-0.02788	0.00500	-5.57	2.555E-08	***
Industrial - 300m	-0.01618	0.00313	-5.17	2.335E-07	***
Golf - 1500m	0.00269	0.00034	7.99	1.392E-15	***
Park - 1500m	0.00205	0.00037	5.59	2.288E-08	***
Sugarcane Farmland - 1500m	0.00070	0.00010	6.83	8.714E-12	***
Commercial - 1500m	0.00293	0.00028	10.57	< 2.2e-16	***
Industrial - 1500m	-0.00077	0.00010	-7.60	3.098E-14	***
Golf - 5000m	0.00209	0.00010	20.55	< 2.2e-16	***
Park - 5000m	0.00077	0.00009	8.66	< 2.2e-16	***
Commercial - 5000m	0.00030	0.00005	6.52	7.095E-11	***
Industrial - 5000m	-0.00006	0.00001	-3.72	0.00020	***
NatVeg300m_1	0.00470	0.00167	2.82	0.00478	**
NatVeg300m_3	-0.00878	0.00213	-4.13	0.00004	***
NatVeg1500m_1	0.00049	0.00010	4.80	1.587E-06	***
NatVeg1500m_2	-0.00118	0.00015	-7.95	1.998E-15	***
Neighbourhood Tree Cover	0.00169	0.00029	5.79	7.113E-09	***

Variable	Co-efficient	Standard error	t-value	Pr(>|t|)	p
Rivers300m_1	-0.00025	0.00004	-6.99	2.905E-12	***
Rivers1500m_1	-0.00001	0.00000	-3.53	0.00041	***
Rivers1500m_2	-0.00001	0.00000	-6.27	3.728E-10	***
Rivers1500m_3	-0.00008	0.00001	-7.49	7E-14	***
R-squared				0.8075	

Notes: (1) Continuous independent variables are interpreted as 100(b) to get the percentage change in Y for a one-unit change in X. (2) Categorical independent variables (View, Security, Condition, Garage, Pool) are calculated using the difference in sub-group means between the designated group and the reference group, applying the equation 100[EXP(X)-1]. (3) ***p<0.001, **p<0.01, *p<0.05.

A6.3.2 Structural and neighbourhood effects

The estimated coefficients for the property structural characteristics are all highly significant with the expected signs. Structural variables including square meterage of living area, the presence of a garage and swimming pool, the condition of the property and the security of the property were all positively related and significant at the 0.1% level, as expected. Since the size of the living area in metres squared were log-transformed, as was the dependent variable, this coefficient can be interpreted as elasticity. It revealed that a 1% increase in square meterage of the living area increased the sales price of property by 0.59%. Density (people per km2) has a significant negative effect on housing prices, with property prices decreasing by 0.001% for every extra person per km2. Modal household income was positive and significant with a 0.3% increase in home value for every 1% increase in modal household income; households with higher incomes being able to afford more expensive property. Distance to the nearest independent school was negative and significant with a 1% increase in distance to school lowering house prices by 0.03% per km.

The condition of the house was found to be extremely important, as was security. Properties in a good and average condition have significantly higher prices when compared to those in a poor condition. The percentage decrease in price between properties in an average condition compared to those in a poor condition was found to be 26% (R258 000) and for those in a good condition the change in price compared to those in an average condition was 8.3% (R83 000). Property price decreased by 9% (R87 500) for houses with poor or no security compared to houses with good security. Having a swimming pool and a garage also has a significant positive impact on property price. Property prices increase by 10.4% (R105 000) for houses that have a garage compared to those that don't and 7.4% (R75 000) for houses that have a swimming pool. The view from the property was found to have a significant effect on property prices. Views of informal settlements and commercial areas had a negative impact on property price, whereas those with views of the surrounding landscape, the sea or partial sea had a strong positive influence on property price. However, only sea and partial sea views were found to be significant. Views of partial sea increased property prices by 18.8% and direct views of sea by 26%.

The amount of commercial (or retail), industrial and major road area had significant impacts on property prices at the 300m, 1500m and 5000m scale. The amount of major road network and industrial area had a negative impact on property prices with every extra hectare of industrial area within 300m decreasing prices by 1.6% (R16 150) and for major roadways by 2.8% (R27 900). Commercial areas within 300m were found to have no impact on property prices but had a positive and significant impact at the 1500m scale. A one hectare increase in commercial land within 1500m increased house prices by 0.3% (R2900), indicating the importance of accessibility to shops, shopping centres and restaurants. At the 5000m scale, commercial land was also found to be a contributing factor with property prices increasing by 0.03% (R300) for every extra hectare of commercial or retail area and decreasing property prices for every extra hectare of industrial area by 0.006% (R55).

A6.3.3 Environmental effects

Many of the environmental variables included in the model are highly significant and represent relatively large economic effects. As expected, distance to the coastline was negative and highly significant. The logged distance to coastline variable indicates, with all else constant, price decreases with increasing distance from the coastline, but the rate of decrease lessens with increasing distance from the coast. As a logged variable with a logged dependent, the coefficient of -0.026 can be interpreted as an elasticity, indicating that for each 1% increase in distance from the coastline, there is a 2.6% decrease in value. This highlights the importance that residents place on accessibility and proximity to the coastal environment.

What became clear from the analysis was that the condition of natural open space areas is very important and does have a significant influence on property sales prices within the EMA, especially at the immediate and neighbourhood scale. At the immediate scale (300m radius) natural vegetated open space areas in a good condition had a significant positive impact on property price. For every extra one hectare of natural vegetated open space in a good condition, house prices increase by 0.5% or R4700. However, for every extra hectare of degraded vegetated open space within a 300m radius, house prices decreased by 0.9% or R8700. At the neighbourhood scale (1500m) natural vegetated open space in a good condition increases house prices by 0.05% (R500) for every extra hectare. At this scale, intermediate and degraded natural vegetated open space has a significant negative impact, with every one extra hectare decreasing house prices by 0.12% (R1200). Natural open areas that are not protected formally are often targeted by people moving into the city with no formal place to live. These areas are often transformed into informal settlement sites or are used for gathering natural resources such as fuelwood. Overuse and unregulated pressures from increasing urbanisation results in the degradation of these natural open space areas, resulting in a general decrease in attractiveness of these areas. Degraded open space patches are also often associated with crime, making them even less desirable in terms of their proximity to properties and their accessibility. It was therefore no surprise that degraded natural open space areas had a negative impact on house prices within 300m and 1500m.

Unexpectedly, river systems, regardless of their condition, had a negative impact on housing prices at the immediate and neighbourhood scale. Whilst the percentage decrease on property value is relatively small ranging from 0.001-0.025% (R12 – R250), it is still surprising that even when in a good condition the proximity to rivers is considered negative. This could be that people prefer to have views over river gorges, such as in the areas of Hillcrest and Kloof, but consider rivers in close proximity to property as a negative influence as they are known to attract informal settlements, are prone to flooding and can be considered breeding grounds for unfavourable insects such as mosquitos.

Other types of green open space, such as golf courses and park areas both had a significant positive effect on house prices at the 300m, 1500m and 5000m scale. At the immediate scale, for every extra one hectare of golf course within a 300m radius house prices increased by 2.9% (R29 000) and 1.4% (R14 000) for parks. Similarly golf courses and parks influenced property prices positively at the neighbourhood scale with every extra hectare of golf course increasing house prices by 0.27% (R2700) and every extra hectare of park land by 0.21% (R2000). Sugarcane farmland had a significant positive impact on property prices at the neighbourhood scale with every extra hectare increasing house prices by 0.07% (R700). At the 5000m radius golf courses and park land still had a significantly positive effect, with golf courses increasing house prices by 0.21% (R2000) for every extra hectare and parks by 0.08% (800) per hectare. The "greenness" of each neighbourhood, represented by the percentage tree cover within residential areas was found to be positive and significant. For every extra 1% increase in tree cover, property value increases by 0.17% (R1700).

A6.3.4 The value of well-managed natural open space

The total premium associated with natural open space in a good condition was 2% of overall property value, which amounted to R4.4 billion. When assigned to the relevant open space areas, these areas were estimated to contribute R108 900 per ha on average within the EMA (Figure A6. 2). This is only part of the asset value of these areas, which also provide other ecosystem services. The highest values were located within the main urban core (R1.4 million per ha in Durban MP) and along the coastline where high quality natural coastal forests are still intact (e.g. Umhlanga – R3.4 million per ha). The values were also higher in and around Hillcrest and Kloof (about R1 million per ha), both being affluent areas, much like the coastal suburbs of Umhlanga and Durban MP, whereas they were lower in inland areas such as Cato Ridge (R37 500 per ha) and Pinetown (R423 000 per ha).

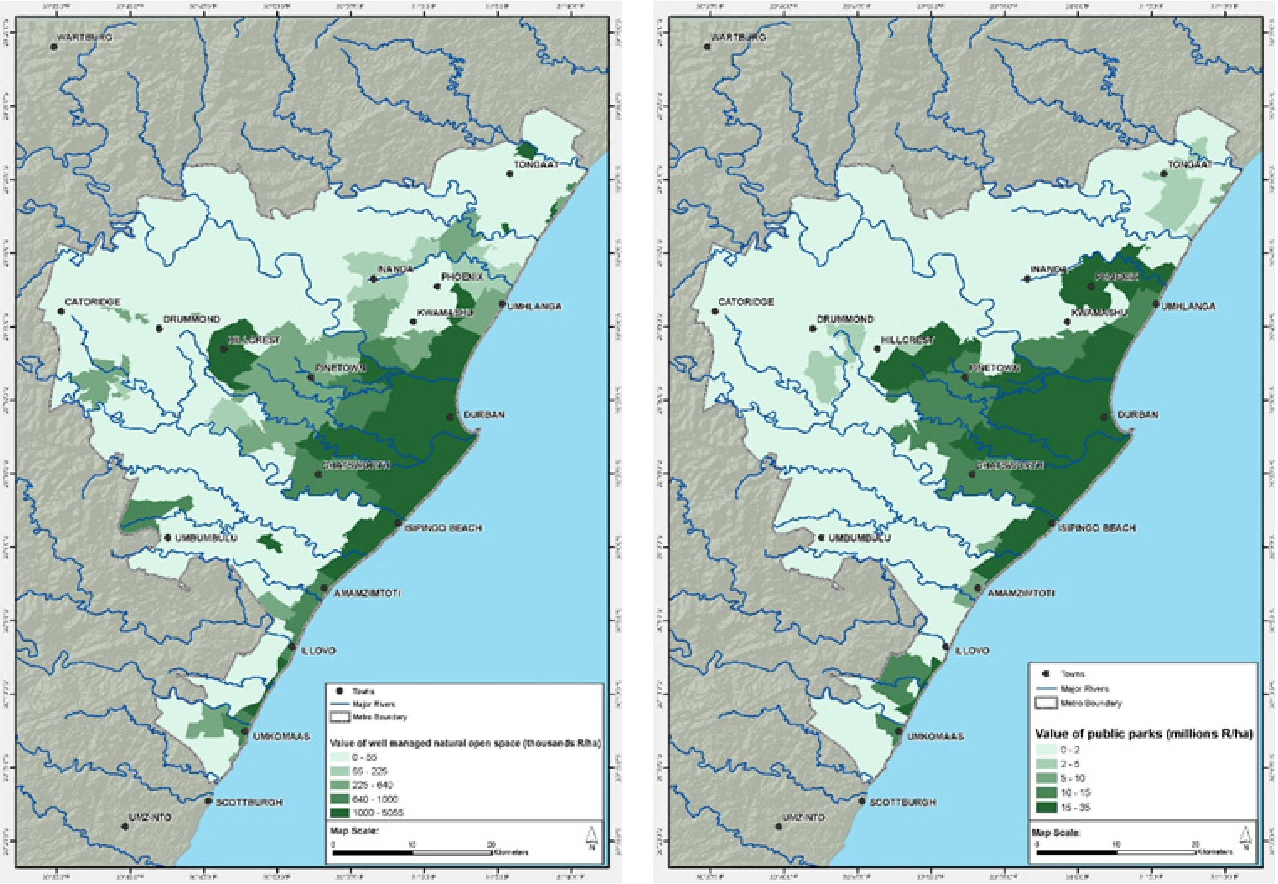

Figure A6.2 Average value (R/ha) of (a) natural open space in a good condition and (b) parks within each main-place within the EMA. Note: the actual location and extent of open space areas within each EMA is not shown due to scale.

A6.3.5 The value of public park land

The total premium associated with public parks was approximately 6.4% of overall property value, amounting to a total of R13.8 billion. When assigned to the relevant parks, these areas were estimated to contribute R14.7 million per ha on average (Figure A6. 2). Park value is highest in and around the urban core of Durban city but is also important in other densely populated areas such as Chatsworth, Phoenix and Pinetown. With an average population density in Chatsworth of 5500 people per km2 and in Phoenix 6400 people per km2, both higher than the EMA average, it is clear why residents in these areas may value public open space more than residents living in less dense areas with larger property sizes. The suburbs surrounding the city centre such as Morningside and Musgrave have a number of public park areas that contribute significantly to the premiums in this area. It is our understanding that urban parks provide a number of opportunities for every day recreation such as jogging, walking dogs and safe areas for children to play. Natural open spaces may provide a beautiful view or a place to walk, but it is assumed that these areas are not utilised in the way that parks can be and as a result are valued less by residents who are seeking a safer and easily accessible environment in which to enjoy green open space in the city.

A6.3.6 Contribution to property rates income

Based on the above, the presence of well managed green open space in eThekwini Municiaplity contributes an estimated R356 million per annum in property tax revenues to the city. This would account for more than 5% of total property rates income to the municipality.

A6.4Conclusions

The eThekwini property market analysis yielded three important insights. The first was that the effect of open space on sales price depends on property location and neighbourhood characteristics, the second was that the condition of the natural open space areas is extremely important, and the third being that the type of open space has a significant influence on property price. The analysis showed that natural open space environments in a good condition have a significant positive impact on property prices and natural areas in a degraded condition have a strong negative impact on property prices. This was evident at both the 300m and 1500m buffer radius highlighting the importance of good quality natural open space and the positive impact it has on house premiums in the EMA. Residents therefore attach amenity value and are willing to pay for access to or views of open space, but only when these areas are in a healthy condition.

The combined value of green open space areas in the EMA, both natural and man-made, was estimated to be R18.2 billion. This study has shown that at the immediate and neighbourhood property scale residents of Durban attach a higher amenity value to man-made parks than they do natural green open space. It is our understanding that safety plays an important part in how people value certain types of open space. It is assumed to be because of the many recreational opportunities that parks offer, such as jogging or playing football, activities that cannot be done easily in natural, densely vegetated areas and that residents seek a safer and more easily accessible environment in which to enjoy green open space in the city.

The results from this research have several management implications. The premium values associated with green open space provide more of an understanding as to how residents in different areas value green open space and these results suggest that city planners and developers need to consider the spatial context of open space areas and how best to provide and protect these areas across the EMA. In Durban it is clear that the type and condition of green open space has a large influence on the value associated with these areas, as does household income and population density. This information can be used to better understand, plan and budget for future development across the EMA and can also be used to highlight the importance of these areas and the need to maintain them. Degraded open areas, however, have a significant negative impact on house prices. This result needs to be examined further in terms of how possible restoration or rehabilitation of degraded areas can increase property value in these areas, or the possibility of developing certain degraded areas into other green open space areas such as public parkland. There are however costs involved in maintaining public park areas and therefore a detailed cost benefit analysis is needed to fully understand how best to provide good quality green open space for the residents of Durban who clearly do value these spaces.

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