Coastal landscape change on the Cape St Francis/St Francis Bay peninsula from 1960 to 2014

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Declaration

The academic requirements for the degree of Master of Science were fulfilled. Rhodes University's plagiarism policy was understood and accepted by the author. Work of other authors that was included in this research project was acknowledged.

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Acronyms

DGPS	Differential Global Positioning System
CSF	Cape St Francis
HBD	Headland Bypass Dunefield
OBHBD	Oyster Bay Headland Bypass Dunefield
SAWS	South African Weather Service
SFB	St Francis Bay
SP Dunefield	Shark Point Dunefield
STATSSA	Statistics South Africa

Acknowledgements

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Abstract

A large proportion of the human population, their settlements and socioeconomic activities occur on land directly adjacent to the coastline. The increased demand for coastal leisure and tourism has interfered with natural landscape features and their associated processes. The Cape St Francis/St Francis Bay peninsula located on the southeast coast of South Africa was rapidly developed and transformed from a little fishing village into an urban coastal developed area over a 50-year period (1961-2014). A system that once existed in a state of dynamic or non-equilibrium was interfered with through anthropogenic disturbances, resulting in more frequent and intense natural events, which ranged from floods to debris flows, decreased sand supply and resulting beach erosion. The aim of the project was to identify and map landscape features and changes on the peninsula using an interdisciplinary approach. The triangulated methods of a desktop study using Geographic Information Systems (GIS) and media reviews, a crowdsourcing/participatory approach based on interviews, and a one year land surveying period of measurable field based surveys of physical features gave a well balanced view. The research showed that the natural landscape has been altered dramatically by settlement and associated infrastructure development. In particular, the loss of dunefields and the artificial modification of river paths were major impact areas. Beach erosion is a continual issue for the peninsula residents, particularly in St Francis Bay.

CHAPTER 1: Introduction

1.1. Background and motivation

It is well known that a large proportion of human settlements and socioeconomic activities occur on land adjacent to the world's shorelines (Small and Nicholls, 2003: 584) with many of the world's largest cities and metropolitan areas located within coastal zones. Australia is a large coastal community where 85 % of the population lives within 50 km of the coastline (Smith, 2001: 73). In South Africa, 40 % of the population resides within 100 km of the coastline. The majority of which reside within one of the port cities, namely Cape Town, Durban or Richards Bay (Palmer *et al.*, 2011: 159). Beaches are also important tourist attractions with countries like the United States of America receiving most of their tourism from their beaches (Houston, 2008: 22). Numerous major coastal cities are becoming overdeveloped and overpopulated resulting in a shift in development focus areas, moving towards the less developed coastal regions (Palmer *et al.*, 2011: 159). These rapidly developing settlements are sites of significant human-induced change to existing coastal ecosystems which increases natural hazards associated with change and impacts on geomorphological processes present in that specific coastal zone (Small and Nicholls, 2003: 583).

Coastal erosion refers to the constant decline in the amount of sand in a beach system without replenishment (van Rijn, 2011: 868) and is a global problem (da Silva *et al*., 2006: 897). It is estimated that 70 % of the world's beaches are eroding (Bird, 2000: 147; Kumar *et al.*, 2006: 531) mainly due to sand supply interruption (da Silva *et al*., 2006: 897). Sand supply can be changed or lost through anthropogenic actions such as dune stabilisation and damming of rivers, as well as through natural process such as climate change (da Silva *et al*., 2006: 897). The continuous population growth and rapid land development in coastal areas increases the risk of property loss or damage from extreme weather events and natural hazards (Tang *et al.*, 2013: 46). Whilst coastlines are often perceived as stable permanent assets, in reality they have a dynamic nature (Phillips and Jones, 2006: 518). This dynamism makes coastal systems vulnerable (Klein *et al.*, 1998: 259). Human and natural processes influence coastal systems in the world over long and short temporal scales (Klein *et al.*, 1998: 259).

Interest in coastal studies has grown significantly in response to sea level rise predictions (Allard *et al.*, 2008: 107) due to future management of coastal zones being significantly undermined by this process (Phillips and Jones, 2006: 517). Wind and wave climates have a strong effect on coastal sedimentary system evolution (Allard *et al.*, 2008: 107). Hard defence structures (for example groynes and seawalls) have been constructed along many coastlines in the world in an attempt to combat beach erosion (da Silva *et al.*, 2006: 897). Beach nourishment (a soft defence method) is considered the most 'natural' answer to the problem (da Silva *et al.*, 2006: 897) as the approach only adds a sand source to the system. When attempting to counteract beach erosion, it is vital to have a thorough understanding of the factors and processes that play an integral part within a particular coastal geomorphological system (Kumar *et al.*, 2006: 531).

The Cape St Francis/St Francis Bay peninsula settlements, along with their socioeconomic activities, are situated close to the shoreline. Coastal systems are considered vulnerable and so disturbing the systems' state of equilibrium may alter the landscape to such an extent that changes may be irrevocable or irreparable (Barnosky *et al.*, 2012: 52). Since coastal development of the peninsula first started in the mid-1950s, this coastal area has been subjected to numerous anthropogenic changes. The result of these anthropogenic changes to the Cape St Francis/St Francis Bay peninsula has led to property damage and the increased threat of loss of human life and property through natural extreme events. The consequences of developing human settlements on driftsand and in low-lying wetland areas have resulted in beach erosion and more frequent flood events during prolonged rainfall periods. This study assesses changes in landscape features on the peninsula over both temporal scales. The best approach to identify long and short temporal changes is to have a desktop analysis (historic, long term perspective) combined with field measurements (short term), and incorporate local stakeholder knowledge (combination of long and short term). Understanding system dynamics is essential to successful management and this research aims to improve our understanding of the Cape St Francis/St Francis Bay peninsula coastal system with a view to aid future management plans. This study does not attempt to cover all the systems and features present on the peninsula as the focus of the research is determined by participants identification of noteworthy issues.

1.2. Research aim

The aim of this research was to determine historic and current coastal landscape changes on the Cape St Francis/St Francis Bay peninsula.

1.3. Objectives

In order to achieve the aim, the following objectives were undertaken:

1. The identification of coastal landscape features present on the peninsula;

2. To determine coastal landscape changes;

3. To investigate selected measurable landscape features; and

4. To use findings to develop an improved understanding of the landscape, which may inform future planning and management of the peninsula.

CHAPTER 2: Study area

2.1. Locality

The study area was the Cape St Francis/St Francis Bay peninsula in the Eastern Cape, South Africa (Figure 1), located approximately 110 km west of the metropolitan city of Port Elizabeth. The peninsula is part of the Kouga Municipality and Cacadu District. Figure 1 highlights the developed areas on the peninsula, specifically St Francis Bay, Cape St Francis, The Marina Glades or The Canals, Santareme, and Sea Vista; two golfing estates, of which only the St Francis Links is labelled; and the nature reserves surrounding Cape St Francis. Nearby towns include Oyster Bay, Humansdorp and Jeffrey’s Bay. The R330 road provides the only entrance into and exit out of the peninsula and crosses the Kromme and Sand Rivers as well as the toe of the Oyster Bay Headland Bypass Dunefield.

The St Francis bay is described as a half-heart bay (Tinley, 1985: 10). There are two active headland dunefields, namely Oyster Bay Headland Bypass Dunefield (extending across the peninsula) and the Shark Point Dunefield (located at the headland close to the Port) (Figure 1). Along with the dunefields, the Cape St Francis/St Francis Bay peninsula coastline is a combination of rocky and sandy shores and features an estuary. These characteristics attract tourists and researchers alike.

Tourist establishments offer water sports, boat cruises, beach visits and fishing opportunities. The 1966 movie ‘The Endless Summer' promoted surfing on the peninsula, attracting many tourists in the peninsula’s early development. The setting and popularity of the peninsula towns has resulted in increased development pressure for second (holiday) homes due to its close proximity to Port Elizabeth.

The desktop analysis maps the area described. The field measurements were conducted on the artificial spit, St Francis Bay, and Cape St Francis beaches as well as the Shark Point Dunefield and the Sand River. Local stakeholders were interviewed in St Francis Bay, Cape St Francis and Sea Vista.

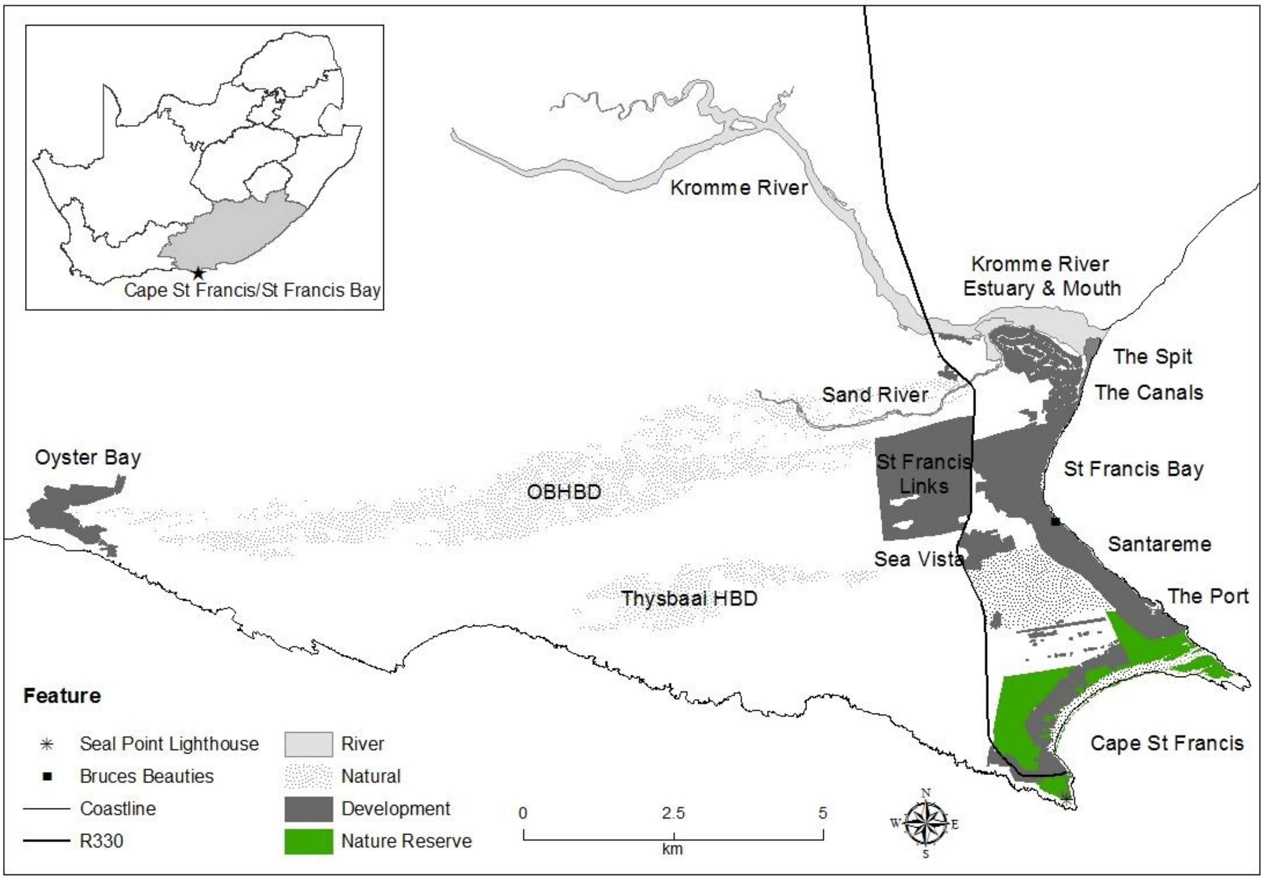


Figure 1: Urban development and natural features on the Cape St Francis/St Francis Bay peninsula

2.2. History

In the mid-1950s the Hulett family settled in modern day St Francis Bay after seeing an advertisement titled “Fisherman’s Paradise, lonely and isolated, well wooded and watered, two miles of private beach” in The Farmers Weekly of 1954 (St Francis Tourism, 2013). A fishing village consisting of eight rondavels was established. Within two years a small township of 51 plots had developed. In 1967 the first canal was dredged which provided an aesthetic ‘little Venice’ in South Africa. St Francis Bay, The Canals and the Hotel developments were completed in the early 1970s. A total of 161 houses were established in St Francis Bay by 1974 and the Santareme development had started. From 1975 to 1977 the Sand River Bridge and the Kromme River Bridge constructions were completed. In 1978 five building companies were operating on the peninsula, and this had increased to 60 by 1983. A year later, 400 houses were established in St Francis Bay. Port St Francis officially opened in 1996. The construction of the first private primary school (St Francis Bay College) was completed in 2004. The St Francis Links Golfing Estate opened in 2006. A full history is provided in the timeline (Figure 26) presented in the results.

2.3. Geology

With land and ocean interacting, the geological environment is unique in its composition as are the physical processes that affect it (Dean and Dalrymple, 2002: 3). Most coastal areas are not tectonically stable (Bird, 2000: 27) and geology controls the landforms present on the landscape (Bird, 2000: 3).

The underlying geology of the peninsula is the Table Mountain Group (Cedarberg and Peninsula Formations, Nardouw Subgroup - Baviaanskloof, Skurweberg and Goudini Formations), which is mainly quartzite (Figure 2). The bay's underlying geology consists of the Bokkeveld Group (Ceres Subgroup and Gydo Formation), which are soft and easily eroded shales. The headlands are formed by the resistant quartzite of the Table Mountain group. The Holocene Dunes formed over the headland as a result of longshore drift supplying sand and the prevailing westerly and south-westerly wind distributing and transporting sand across the dune field. The Kromme River separates the fertile shale soils to its north from the less rich sandstone to its south (Cowling, 2011: 33). A young geological feature is the estuary (Jackson, 2013: 312).

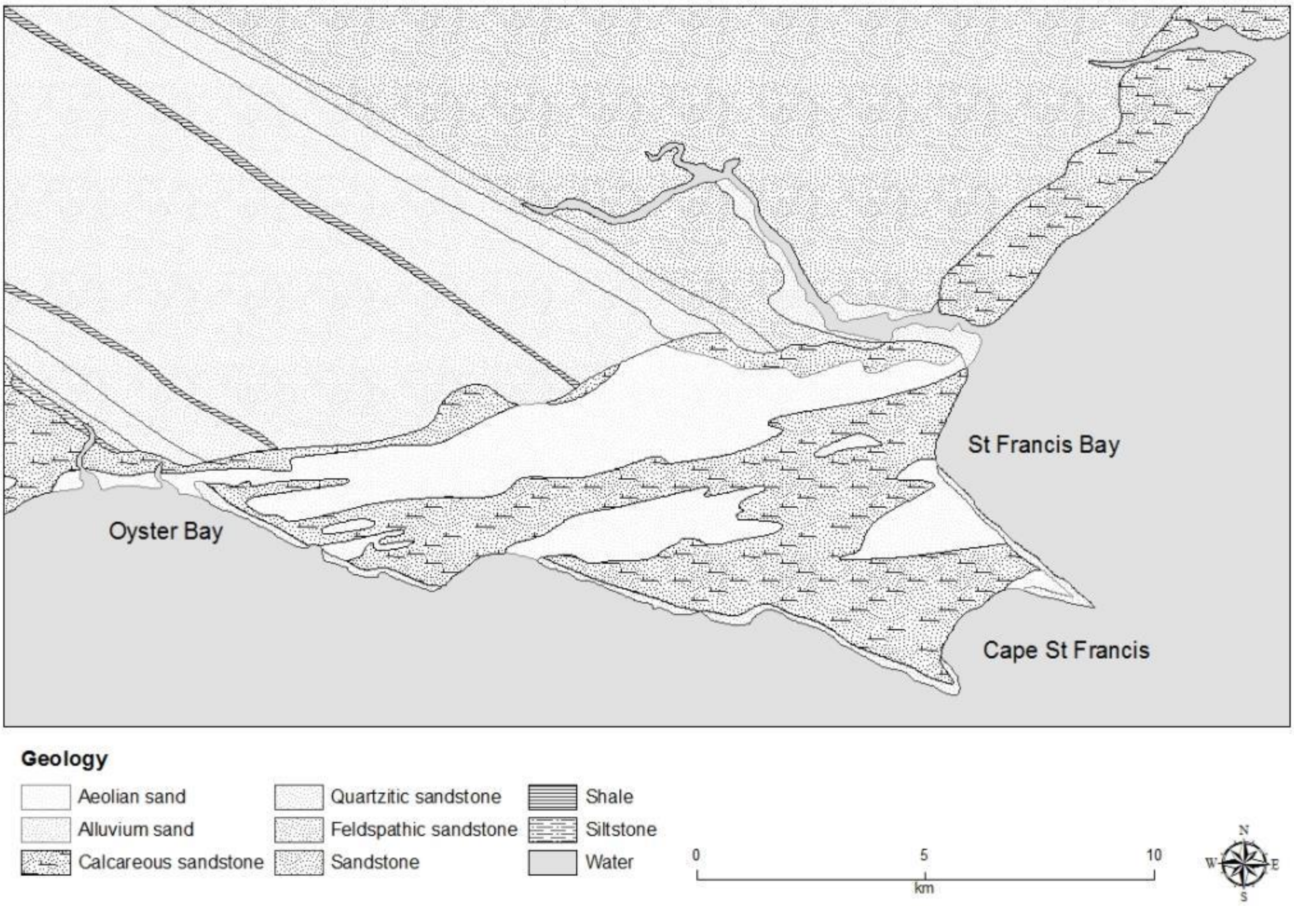


Figure 2: Geology of the Cape St Francis/St Francis Bay peninsula (adapted from Council of Geoscience, 2011)

2.4. Physical environment

Aside from geological influences, landforms are also shaped by a combination of different processes (Woodroffe *et al.,* 2011: 412). Topography can influence which shaping processes are more dominant in some coastal landforms.

2.4.1. Topography

Development is made easy by the predominately flat topography of the peninsula. The dunefields provide relief over the headland and are constantly changing as a result of dunes forming, deforming and reforming depending on the direction and strength of the wind. Elevation varies from a minimum of five meters above sea level (MASL) to a maximum of 211 MASL further inland (Figure 3). There is more variable topography on the western section of the peninsula, with higher elevations than in the east. The lower topography in the east could be a result of the Kromme River and estuary.

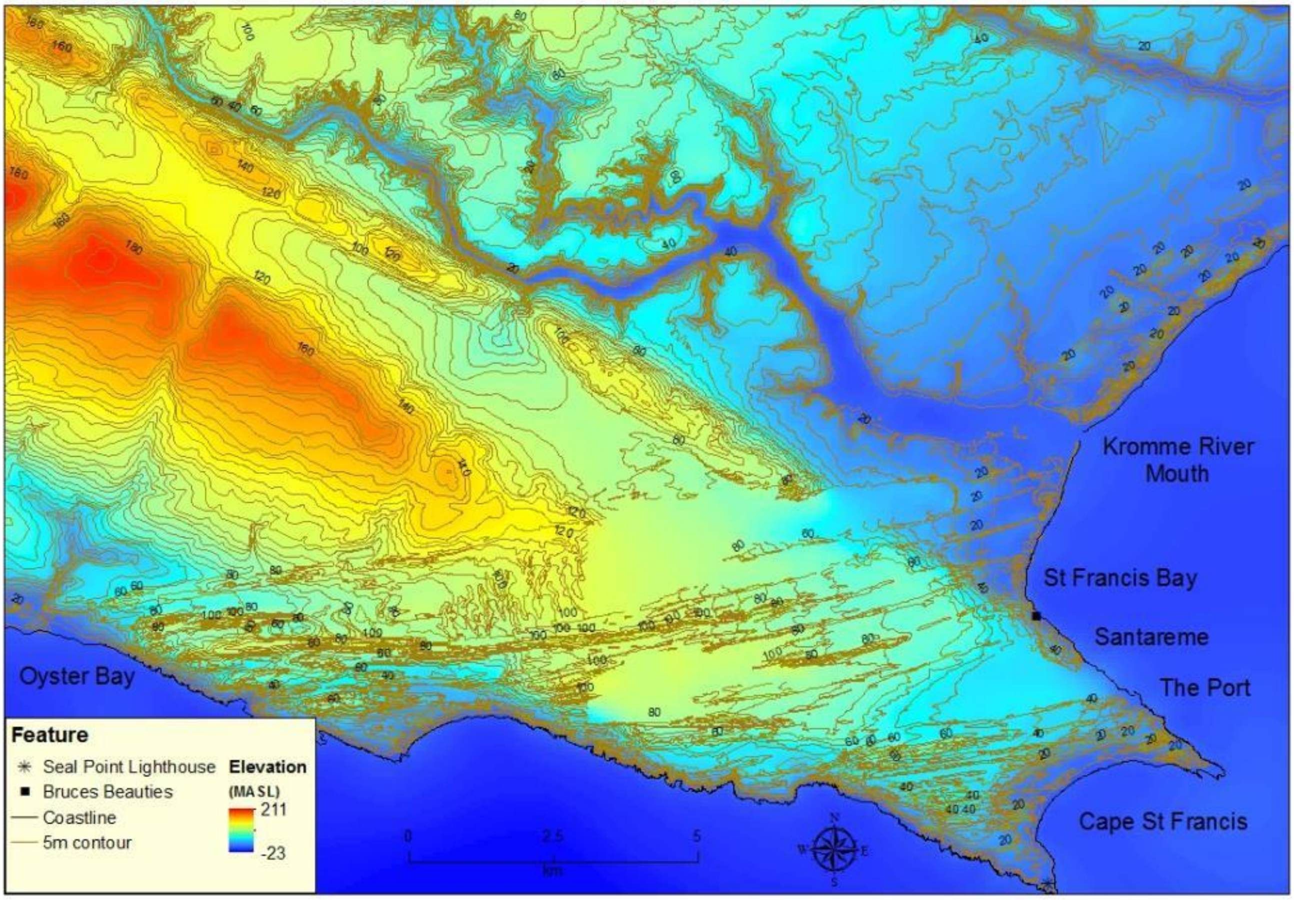


Figure 3: Topography of the Cape St Francis/St Francis Bay peninsula

2.4.2. Landscape features and processes

Human-made and natural landscape features are present on the Cape St Francis/St Francis Bay peninsula. Existing human-made features include urban settlement, industry, the Port, the artificial spit, two golf courses, two dams and numerous drainage ditches. There are also areas of alien invasive stabilised land. Natural features present are the Kromme and Sand Rivers, the estuary, dunefields, and sandy and rocky beaches (involving the littoral zone and wave action). Natural factors that influence the shoreline development and changes over a long term period include sediment supply, littoral transport, and secular sea level changes (Kumar *et al.*, 2010: 133).

Kromme River estuary and dams

St Francis Bay is situated in the Kromme River catchment area. The 95 km long Kromme River originates in the Blueliliesbush Forest Reserve in the Tsitsikama Mountains and ends in a 14 km long open estuary (Heymans and Baird, 1995: 40). The estuary is permanently open to the ocean resulting in the estuary being dominated by tidal regimes (Anderson, 2008: 26; Jackson, 2013: 314). In the 1960s the St Francis Bay development, named The Canals, was built along the Kromme River mouth (Heymans and Baird, 1995: 40). An artificial spit was constructed 500 meters from the beach into the estuary with the dredged sand from the canal construction; this spit has limited natural movement of the Kromme estuary. The Kromme River is dammed by two large dams: the Churchill and Mpofu. Dams storing large volumes of water often disrupt natural drainage systems which affects the transfer of sediment and hydrology (Abam, 1992: 60). These dams suffer from siltation, as the predicted siltation rate is often much slower than the real siltation rate (Carley and Christie, 1992: 27). Lessened flow through the river caused by damming and abstraction from agriculture has resulted in salinity changes and the siltation of the estuary.

Wetlands, aquifers, and dune pans

Wetlands are natural filters of toxins from water sources and lessen flooding impacts (Carley and Christie, 1992: 26). Major changes to the Kromme catchment wetlands as a result of agricultural activities have increased the susceptibility of the catchment to flooding (Rebelo *et al.*, 2013: 337, 345). The whole catchment can be affected by the loss of wetlands, not solely the surrounding fields (Herzon and Helenius, 2008: 1172). There is little agricultural runoff, industrial effluent and sewage waste from present developments entering the river

(Heymans and Baird, 1995: 41). Alien invasive plant species, such as Black Wattle (*Acacia mearnsii)* need to be removed for the flow of the Kromme River to improve (Rebelo *et al.*, 2013: 345). Aquifers have the same capability as wetlands, but this still requires further investigation (Rebelo *et al.*, 2013: 341). There is an aquifer located under the Sea Vista Township. Dune pans form in the depressions of inter-dunal areas. Pans in the eastern section of the Oyster Bay Headland Bypass Dunefield are drained by the Sand River. Development, particularly the St Francis Links Golf Course, prevents natural drainage to some degree (Geldenhuys, 2012: 2).

Dunefields

Extensive dunefields are common on half-hearted bays and their headlands (Tinley, 1985: 74). Dunefields are prominent and significant features of the Cape St Francis/St Francis Bay peninsula (and fossil dunes can reach a height of 80 meters and move eastwards (Rust, 1998: 23). Dunefields are major contributors to the littoral active zones of the coastal system - some of which are completely stabilised, such as Santareme and Thysbaai. The Oyster Bay Headland Bypass Dunefield extends across the peninsula from Oyster Bay to St Francis Bay and has been partially vegetated and stabilised (Tinley, 1985: 29), but the system is still considered to be active.

Littoral zone

The area between the neap high water and spring high water mark is the littoral zone (Lubke and Seagrief, 1998: 66). It is important that a stable supply of sand enters the littoral active zone to prevent erosion (Tinley, 1985: 236). Loss of the sand source due to supply interruption or dune stabilisation can negatively impact the equilibrium of the coastal system as in the case of the St Francis Bay beach. The stabilisation of the toe of the Oyster Bay Headland Bypass Dunefield has disrupted the constant supply of sand from the land to the ocean and as a result the littoral active zone has now progressed landwards causing the loss of beach width. The peninsula beaches are impacted by wave regimes. In St Francis Bay the Kromme River and estuary, beaches and beach dunes, sand banks formed in the surf zone and headland bypass dunefields comprise the littoral active zones (Tinley, 1985: 199). These four areas act as sand sources and sinks at different times (Tinley, 1985: 199).

In St Francis Bay the entire beach can be classified as the littoral zone as spring high tides reach the revetments which are the furthest point from the ocean on the beach (Lubke and

Seagrief, 1998: 66). In comparison, the upper beach of the Cape St Francis contributes sand to the littoral zone via beach dunes and the lower beach adds to the littoral zone with beach sand. The upper beach is situated at an estimated eight MASL (Tinley, 1985: 83) and the spring high tides do not reach the beach dunes.

Wave action

Southern African coastlines have characteristically strong wave actions (McLachlan *et al.*, 1994: 201) and this, along with storm surges, can erode beaches (Houser and Ellis, 2013: 267). Anderson (2008: 5, 6) observed that waves primarily come from the southwest and that high energy waves are often experienced on the peninsula but the shape of the peninsula means that the wave regime is variable. Consequently, the headland protects St Francis Bay from westerly wind-driven waves, but easterly wind-driven waves have no barriers and thus no energy is lost, heightening beach erosion. Furthermore, waves hit the shoreline obliquely which promotes erosion. Nonetheless, longshore drift carries sand from dunefields onto the St Francis Bay beaches.

2.5. Climatic variables

2.5.1. Rainfall and temperature

The mean monthly rainfall varies between 20 and 130 millimeters (Figure 4). The peninsula receives the highest amount of rainfall in winter (May – August), but other high rainfall periods may be encountered throughout the year (often in November) (Tinley, 1985:12) (Figure 4). Highest rainfall periods are experienced during cut-off lows, followed by the Southerly/South Easterly wind (Cowling, 2011: 32, 33). The average midday temperature on the peninsula is 18.5 ℃ in July and 24 ℃ in February (Anon, 2011).

2.5.2. Wind

Strong coastal winds are typical for the Eastern Cape (McLachlan *et al.*, 1994: 201). There is a weak land breeze in Cape St Francis, growing stronger in upper St Francis Bay (Tinley, 1985: 89). Spring and early summer (September to January) is the windy season for the Cape St Francis/St Francis Bay peninsula (Cowling, 2011: 32). The prevailing wind is from the west and is known to facilitate dune formation (Illenberger and Burkinshaw, 2008: 71; Figure

5). The coastline experiences bidirectional winds depending on the season (Tinley, 1985: 9, 89). Westerlies are experienced throughout the year but less often in summer and spring when the Easterlies are more prominent (Tinley, 1985: 89). The low relief of the peninsula means strong winds influence a large area, with the Easterlies reversing the effects of the Westerlies. The northern areas of St Francis Bay have a stronger land breeze than in Cape St Francis (Tinley, 1985: 89). The Westerlies bring warmer water to the coastline while the Easterlies allow the upwelling of colder water (Sauer *et al.*, 2007: 63).

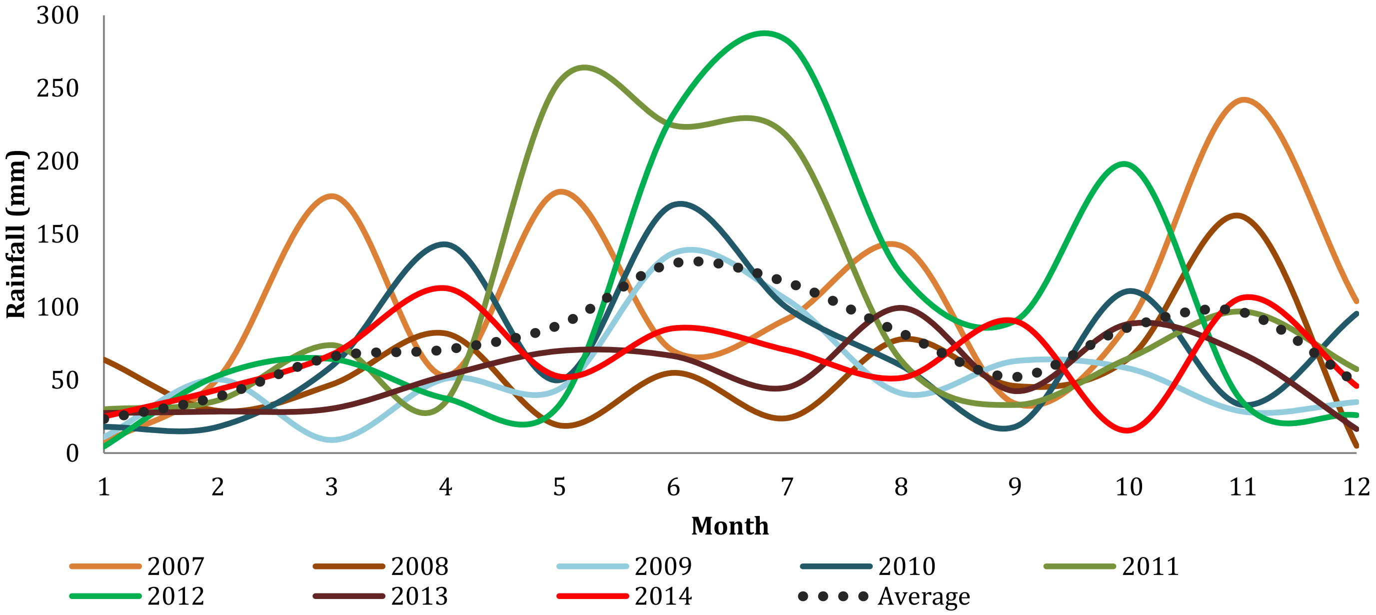


Figure 4: Average monthly rainfall from 2007 - 2014

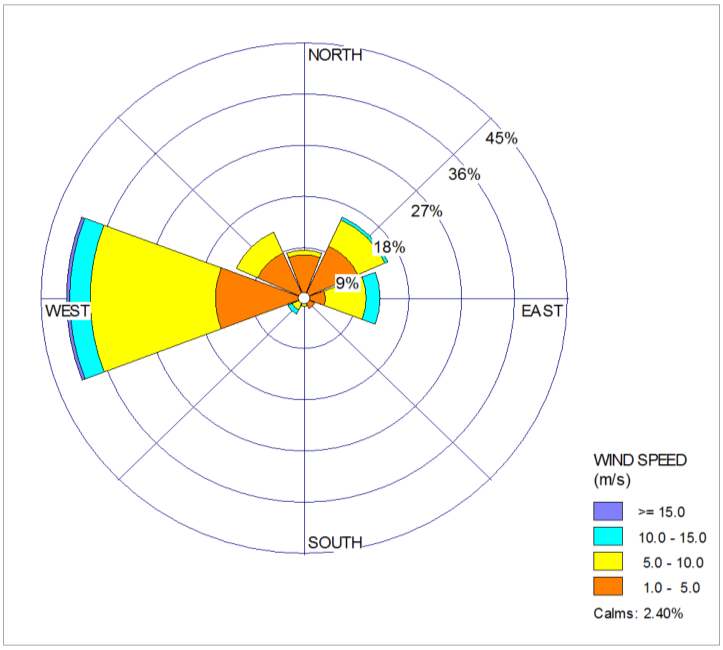


Figure 5: Wind rose displaying direction and speed over the surveying period (adapted from South African Weather Station, 2013 and 2014)

2.6. Vegetation

The peninsula is located in the Cape Floristic Region with the main vegetation type being Fynbos. An estimated 9 000 plant species grow in this region (Cowling, 2011: 32). There are a large number of endemic plant species in the Cape Floristic Region and the high density of these species cannot be matched anywhere else in the world (Holmes and Cowling, 1997: 316). Few of the vegetation types are protected (Cowling, 2011: 38). There are three types of Fynbos found in this region described by Cowling (1984), namely the South Coast Dune Fynbos, the small dune thicket and Kaffrarian Thicket Mosaic. The Thicket Mosaic is dominant in larger Cape St Francis area (Cowling, 2011: 35). Fire has an important role in the lifecycle of Fynbos species.

Alien invasive species easily outcompete the South Coast Dune Fynbos as this type of Fynbos is very sensitive (Lubke, 1985: 114). The alien invasive plant species Port Jackson Willow (*Acacia saligna*) and Rooikrans (*Acacia cyclops*) were introduced in an attempt to stabilise and manage a number of dunefields systems in St Francis Bay and Cape St Francis. It was this stabilisation that resulted in an interrupted sediment movement in the dune systems. When alien invasive species take hold of an area they decrease species diversity by outcompeting other species and changing the natural processes at work (Holmes and Cowling, 1997: 317). *Acacia* species mature quickly, where a total growth of three meters or higher can be achieved, and produce huge amounts of seeds (Holmes and Cowling, 1997: 317, 327). They are also fire resistant (Holmes and Cowling, 1997: 317) and can spread more rapidly after a fire when the Fynbos plant species are renewing their lifecycles. However, the high density of these aliens means that the plants still burn and are a fire hazard (Cowling, 2011: 34). Coastal bush and thicket are also fire resistant but cannot spread as quickly as *Acacia* species. Continual burning destroys these plant species and reduces regeneration rates (Cowling, 2011: 36). The fire disturbance on the peninsula increases the presence of these invasive species. The alien species also absorb more water than natural vegetation by draining wetlands and lowering the water table. Working for Water progressively removes the invasive species and homeowners are encouraged to do the same on their properties.

There are four nature reserves on the peninsula and a marine reserve (protecting a sea otter habitat), namely the Wild Cape St Francis Nature Reserve, the Seal Bay Nature Reserve, the Seal Point Nature Reserve, and the Irma Booysen Flora Reserve.

2.7. Fire

The peninsula frequently experiences fires. Bushfires spread quickly through tracts of alien invaded veld and are boosted by strong winds over the peninsula. The threat of fire damage is very real for property owners in St Francis Bay and The Canals. The close proximity of houses and the associated thatch rooftops encourage fire to spread. In 1988 fire spread from the Kromme River estuary, across St Francis Bay, to the lighthouse, where damages amounted to an estimated R2 million. The most devastating fire was on 11th November 2012 where 76 houses were destroyed, amounting to R500 million worth of damages (Mortimer, 2012).

2.8. Socio-economic characteristics

Humans have always built structures in coastal regions (Dean and Dalrymple, 2002: 4). Phillips and Jones (2006: 518) explain the major human activity spheres that are commonly found in coastal zones, which include residency and recreation, industrial and commercial, waste disposal, agriculture, aquaculture and fishing, conservation, military and strategic of which all still hold true today. Of all the activities that are present in coastal zones, none have increased in size and diversity as much as coastal tourism and recreation (Hall, 2001: 602), which was also seen on the peninsula. Recently, recreation and tourism on shorelines have become increasingly important characteristics of coastal developments. Coastal development includes housing and business properties, ports, navigational jetties, and dams (Dean and Dalrymple, 2002: 4). Coastal development causes significant conflict with natural coastal processes (Dean and Dalrymple, 2002: 4).

Nonetheless, the development of accommodation, restaurants, and second homes continue, while the infrastructure supporting development includes retail businesses, marinas and activity suppliers (Hall, 2001: 602). The severe beach erosion in St Francis Bay has created a need for businesses to focus on placing and maintaining rock revetments. The business sector evolves as the environment changes. Properties are required to follow strict building regulations in St Francis Bay and The Canals to maintain the ‘fishing village’ appearance (thatch roofing and white plaster). Building regulations have been adjusted after the 2012 fire, accepting dark roof tiles. This change has impacted on the thatching industry. The housing developments provide economic opportunities for many peninsula residents (Municipal document, 2007: 7). The Canals are a significant source of income for the Kouga

Municipality with the high rates they pay (Municipal document, 2007: 7). The artificial spit protects The Canals from the ocean however this feature is continually eroding. Without the protection of this spit, properties would be lost and the canal system would be highly impacted.

An estimated 6 000 people live on the peninsula. The majority reside in St Francis Bay whilst the least number of people live in Cape St Francis (Table 1). The main socioeconomic activities on the peninsula center around the tourism sector, especially recreational water-based activities such as beach visits, surfing, windsurfing, speed boating, jet skiing and fishing. Tourism provides employment for many individuals (Municipal document, 2007: 1). There are several rentals, 'bed and breakfast' and guesthouses that boost the tourism sector. There are negative impacts related to tourism activities such as environmental degradation. This includes pollution and erosion, particularly over the main holiday seasons such as Easter and Christmas. Tourism is negatively impacted by natural disasters yet areas considered to be 'high-risk' have not lost their appeal to tourists (Faulkner, 2001: 136).

Table 1: Population size of the peninsula (STATSSA 2011 Census)

Settlement	**Population**
St Francis Bay	4933
Cape St Francis	342
Sea Vista	396
Oyster Bay	674
All settlements	6345

On the Cape St Francis/St Francis Bay peninsula agriculture (such as dairy, sheep and beef farming), fishing and retail contribute a large component to the general economy. The bay is a prime area for chokka fishing, because the Easterlies result in an upwelling of nutrient rich cold water (Schumann and De Meillon, 1993: 323). Port St Francis supports the chokka (squid) industry and docks leisure boats as well. Consequently pollution from the harbour is a threat to the marine ecosystems (Hall, 2001: 606).

The St Francis Bay area has two golf courses: the St Francis Bay Community Golf Course (established 1975) and the St Francis Links (established 2006). These golf courses are popular with the residents (St Francis Bay Community Golf Course) as well as tourists (St Francis Links). The St Francis Bay Community Golf Course is more affordable and many players are retired and or were previously disadvantaged. The tourism industry benefits from these golf courses through the tournaments held, the lodges and the event venues there. There are disadvantages to having these features in an area. Resorts and golf courses increase environmental degradation, through the removal of natural vegetation and inclusion of artificial water sources while absorbing more water than a natural ecosystem and contributing to pollution (Hall, 2001: 608). Septic tanks, inadequate sewage systems of some resorts, and the fertilizer runoff from golf courses will negatively impact on the environment (Hall, 2001: 608). Sewage problems are common in coastal areas where after heavy rainfall periods, the raised groundwater level can bring up contaminated water which eventually flows into the ocean. Beach dunes are a barrier between the St Francis Bay Golf Course and the beach. If these dunes were breached, two holes of the course would be lost which might render the golf course economically unsustainable leading to major employment losses.

A Nuclear-1 power plant is to be constructed on the peninsula. This power plant will be the largest in South Africa (Smith, 2013). In general, the public is against the nuclear development; however there is a high likelihood of construction as the nuclear power is part of South Africa’s Integrated Resource Plan (IRP) 2010-2030 to check greenhouse gas production by 2020 and 2025 as outlined in COP 15. If this power plant is impacted by an extreme event the results will be disastrous with inevitable severe environmental degradation. This effect will feed back into and influence human systems.

CHAPTER 3: Literature review

3.1. Introduction

Changes to the biosphere started when humans first began to form settlements, search for food and eventually farm crops and keep animals. However, the biggest changes to the biosphere came with the industrial revolution when natural resources became more important for economic development, the agricultural revolution where intensive farming became the norm and the medicinal revolution because of lowered death rates as a result of vaccinations and cures. The 1900s saw the greatest anthropogenic change to the Earth (Ellis *et al.,* 2010: 602). Humans have impacted most areas on the Earth with landscapes and processes of numerous ecosystems being altered (Ellis *et al.*, 2010: 5, 89). The natural functioning of an ecosystem is highly dependent on the level of human impact (Ellis *et al.*, 2010: 590).

There is abundant literature stating the importance of ecosystems as they support all life forms through the provisioning of various goods and services that benefit ecological and human systems. Striving for economic growth has resulted in the environment being severely degraded across the world (Elliott, 1998: 1). Many people are ignorant or have chosen ignorance when it comes to humanity's dependence on ecosystem goods and services because there is a lack of understanding and an unwillingness to change behaviours when necessary. There have been attempts to value ecosystem goods and services in monetary terms but the total 'value' cannot be accurately quantified in these assessments (Fagerholm *et al.,* 2012: 422). The inclusion of expert knowledge can aid the valuation process (Grêt-Regamey *et al.,* 2013: 34). Changes to the biosphere ultimately resulted in adapting human systems (Carpenter *et al.,* 2006: 29). Coastal zones offer an array of ecosystem goods and services which was why these zones historically attracted human settlements and activities (Palmer *et al.,* 2010: 118). Coastal ecosystems (beaches, dunes and estuaries) are especially vulnerable to human impacts because of their fragility (Webley and Hall, 1998: 429). The need to stabilise the coastline to protect development and so most coastal ecosystems have experienced anthropogenic changes.

To assess the level of human impact in an area, Ellis and Ramankutty (2008) suggested the use of anthromes (anthropogenic biomes). It must be noted that despite anthromes being generalisations, they aided in understanding ecosystems within a biome (Ellis *et al.,* 2010:

599). Ellis *et al.* (2010) built on this concept by looking at human impacts in classic biomes or "potential natural vegetation". The anthrome classes included settlement types and different agricultural activities (Ellis *et al.*, 2010: 591). Results showed that 95 % of the anthromes on the ice-free biosphere in the 1700s were "wildlands and seminatural" (Ellis *et al.*, 2010: 593). This percentage decreased to 45 % by 2000. Biomes that were altered first to meet conditions for settlement and agriculture were the savanna and grassland biomes, where more than 80 % of the areas had undergone anthropogenic change; while harsher environments like the boreal forests and tundra as well as deserts have seen no more than 20 % of change (Ellis *et al.*, 2010: 595). The mapping of anthromes did not include all coastal areas (Ellis *et al.*, 2010: 590), for example coastal dunes. In 1990 coastal areas along the Eastern Cape coastline were included in the "seminatural" (inhabited treeless and barren lands) and "wild" (wild treeless and barren lands) anthromes. By 2000 the area could be considered part of the "rangelands" (remote rangelands or populated rangelands) anthrome. With continual changes to an anthropogenic biosphere, it became imperative that humans understand (past, present and predictive future) and manage the ecosystems in order to preserve their functioning (Ellis *et al.*, 2010: 604). Coastal areas are considered vulnerable in the context and awareness of global climate change (for example sea level rise) (James and Hermes, 2011: 92, 145) and South Africa regards climate change as a key concern (Ziervogel *et al.*, 2014: 605). Knowledge gaps focusing on long-term adaptive monitoring scenarios exist and this warranted future research (Ziervogel *et al.*, 2014: 606). However, South Africa has limited experience with climate adaptation, monitoring and evaluation scenarios; even though the South African government has made it a priority (Ziervogel *et al.*, 2014: 610). In South Africa, only two cities have developed climate change strategies though quantitative impact modelling, specifically Durban and Cape Town (Ziervogel *et al.*, 2014: 609).

If degradation of the environment cannot be prevented, negative impacts must be mitigated and managed (Elliott, 1998: 2). The ability of a society to manage socio-ecological feedbacks determined the continuation of that society (Carpenter *et al.*, 2006: 29). Due to the socio-ecological feedbacks, a community and even a country can become environmentally and economically fragile (Elliott, 1998: 2). The fragility of human systems has been emphasized with recent disasters where damage was extensive and recovery expensive, e.g. tsunamis (Goodchild and Glennon, 2010: 231). Public participation allowed community members to express concerns, increased accountability and promoted acceptance of decisions; thereby encouraging environmental justice (Benn *et al.*, 2009: 1572). From the 20th century, legislation has been contested because of improved understanding of the anthropogenic impacts on the environment (Ebbesson, 2010: 414) and a public participation component has now been included in many statutory legislative processes like Environmental Impact Assessments (EIAs). The inclusion of local stakeholders into research has gained recognition as a viable scientific method because of the extra knowledge added to the study.

This literature review provides insight into coastal geomorphology by specifically looking at global and local coastal erosion; the geomorphological landscape features present on the Cape St Francis/St Francis Bay peninsula and the driving processes that change these features. Beach erosion defence approaches are discussed and a triangulated method approach is explained. Knowledge regarding natural and anthropogenic impacts on coastal zones and shorelines is presented and the Driver-Pressure-State-Impact-Response (DPSIR) Framework is described.

3.2. Coastal geomorphology

Geomorphology aims to understand how landscapes change over time by studying landform features (Scatena and Varrin, 2010: 689; Allen *et al.*, 2011: 138). The close and dependent relationship humans have with their surrounding environment promotes the need to understand the processes and patterns involved in landscape evolution, as well as the flow of materials across landscapes (Scatena and Varrin, 2010: 689). This has been considered an essential component of human knowledge since ancient times (Scatena and Varrin, 2010: 689).

Coastal geomorphology involves understanding one of the most dynamic areas on the Earth, known as the coastal zone (Woodroffe *et al.*, 2011: 412). While the coastline or shoreline definition should have considered spatial and temporal aspects, many studies followed different definitions because shoreline determination is subjective (Boak and Turner, 2005: 688, 699). This study followed the definition of the shoreline being a dynamic boundary between sand and water (Boak and Turner, 2005: 688). This dynamic nature made shoreline change estimations difficult (Reeve and Spivack, 2004: 661). Globally, approximately one third of ice-free coastlines are covered with dunes and sandy beaches (Barbier *et al.*, 2011: 183).

Coastal geomorphological landforms seen on the Cape St Francis/St Francis Bay peninsula included dunes, beaches, an artificial spit and an estuary. The coastal geomorphological processes acting on the peninsula were wind, wave, aeolian and fluvial processes.

3.2.1. Coastal geomorphological landforms on the peninsula

Dunefields

Dune development is determined by the coastline formation and associated landforms as well as climatic variables, sand supply, waves and currents, wind regimes, and plant species presence and abundance (Tinley, 1985: 13). Headlands or peninsulas protrude from the coastline resulting in concave bays. Headlands protect the bays from wave energy. Some headlands erode and this sediment would be transported to the bays (van Rijn, 2011: 867). More resistant headlands provided natural protection (van Rijn, 2011: 868). Headland bypass dunefields form and migrate across peninsulas with a dominant wind (Boeyinga *et al.*, 2010: 152). Coastal dune systems supply sand to and are supplied with sand by beaches (Tinley, 1985: 10). The Cape Recife Headland Bypass Dunefield located in Algoa Bay was regarded as the largest of these driftsand dunefields, which covered a distance of over 18 kilometres. This dunefield was active and fully functioning prior to its stabilisation to protect the jetty of the emergent Port Elizabeth city (Illenberger and Burkinshaw, 2008: 96, 97). Noordhoek dunefield, close to Cape Recife, has been stabilised since the 1970s (Illenberger and Burkinshaw, 2008: 96, 97).

The Oyster Bay Headland Bypass Dunefield was the largest dunefield on the peninsula. It was supplied with sand by the Oyster Bay beach and in turn supplied sand to the St Francis Bay beach. The Thysbaai Bypass Dunefield was smaller and is no longer active. Prior to stabilisation, the Thysbaai Dunefield supplied sand to the Santareme Dunefield on the St Francis Bay coast. The dunefields on the peninsula were primarily aeolian sand sources and many small dunefields were lost over time.

Beaches

Beach profile and shape change at different rates over time (Bird, 2000: 95). Beaches tend to experience seasonal morphology changes; some experience deposition and therefore growth (prograding) while other beaches erode (receding) (Bird, 2000: 95). Beaches undergoing deposition generally have a convex profile, while eroding beaches characteristically have a concave profile (Bird, 2000: 127). The shoreline can change centimetres or several meters during tidal cycles (Boak and Turner, 2005: 689). Over a longer temporal scale (100 years), the shoreline can change by more than 100 meters (Boak and Turner, 2005: 689). Coastlines comprised of beaches have a material composition of loose sediments (gravel, sand or mud) and these were constantly acted upon and shaped by waves, currents and wind (Dean and Dalrymple, 2002: 3). Beach sand sources include eroded landforms like cliffs and upper beaches, sea bed sediment, fluvial sediment, aeolian sediment and human actions such as sand bags and dredging (Bird, 2000: 98, 102, 104, 109).

A rocky beach is also present in St Francis Bay where the Santareme development is situated between Oyster Bay and Cape St Francis (Figure 11).

Rivers

The Kromme is the largest river on the peninsula. There are multiple tributaries that converge with the Kromme River and estuary, namely: the Sand, the Dwars, the Geelhoutboom, the Klein, the Huis, the Brakfontein and the Boskloof River. Prior to the two dam constructions, the intensity of the Kromme River flooding regularly removed sediment that had accumulated at the estuary mouth (Anderson, 2008: 7). The capacity of the two dams is greater than the mean annual precipitation of the Kromme River Catchment, which has resulted in the system seldom experiencing natural flooding. The sluices of the Churchill Dam are permanently closed in the dry season (Watling and Watling, 1982: 187).

The Sand River flows into the Kromme River estuary above The Canals. Little streams join to form the Sand River, which sporadically drains the eastern section of the Oyster Bay Headland Bypass Dunefield. For this reason, fluvial processes transported more sand to St Francis Bay than aeolian processes in the eastern section of the dunefield (Schroeder, 2012: 33). The discharge and flooding of the river was directly linked to the amount of rainfall received (Schroeder, 2012: 35). A staggering 140 000 tonnes of sediment was transported down the Sand River in a single day during a flood in 2011 (Ellery Pers. Comm., 2012). The 2011 flood destroyed the Sand River Bridge and indigenous vegetation, deposited sand on properties on the banks of the Kromme River and damaged the water supply pipeline of Cape St Francis and St Francis Bay (Geldenhuys, 2012: 4). The St Francis Links artificially diverted water away from the golf course after the 2006 and 2007 floods into an inter-dunal depression (Geldenhuys, 2012: 5). The increased water volume in this depression was seen as a major reason for the 2011 flood (Geldenhuys, 2012: 5). The removal of alien invasive species is also perceived to be a contributing factor (Geldenhuys, 2012: 6).

Both rivers had their natural watercourses changed. The Kromme River mouth cannot migrate along the beach as The Canals development became a permanent barrier. The path of the Sand River has been altered with a berm to protect the canal system (Geldenhuys, 2012: 3). The expansion of The Canals prompted this construction in the early 1970s (Geldenhuys, 2012: 3). There was erosion of the berm during the 2011 Sand River flood (Geldenhuys, 2012: 7). Prior to artificial barriers controlling the channel movement, the mouth of the Sand River moved along the Kromme Estuary. As with any river, these artificial changes to the systems led to modifications in hydrology and sedimentology processes (Chin *et al.,* 2013: 810). Channelization, drainage systems and construction of artificial barriers and structures are fundamental to all coastal developments to ensure protection of the development (Chin *et al.,* 2013: 812). Despite these changes, the Sand River floods seem to be unpredictable and unmanageable (Schroeder, 2012: 36).

Estuaries

Some of the most complex features in the coastal zone are estuaries (Jackson, 2013: 308). Estuaries are important and beneficial coastal ecosystems that conjoin land and ocean and they are often degraded through human activities (Barbier *et al.*, 2011: 169, 170). The benefits of an estuarine ecosystem include regulating water quality and erosion as well as providing a safe breeding and spawning area and a productive feeding ground for aquatic animals and birdlife (Barbier *et al.,* 2011: 170; Jackson, 2013: 308). Estuaries also provide benefits to humans by providing services like tourism and recreational activities (Barbier *et al.,* 2011: 170; Jackson, 2013: 308). Goods such as water and resources can be harvested from the estuary (Barbier *et al.,* 2011: 170). An estuary is considered positive when ocean salinity is higher than estuarine salinity levels and when the salinity of the estuary is higher than ocean salinity the estuary is negative (Jackson, 2013: 311). Negative estuaries experience lower freshwater inputs than evaporation rates (Jackson, 2013: 311).

The Kromme Estuary can be considered positive and was a fluvial sediment source for the Cape St Francis/St Francis Bay system but its contribution is now limited. This estuary continues to provide human benefits but ecological benefits are lessening which impact on estuarine life. Consequently, the estuary's function to protect the coast is failing.

Spits

Spits are sensitive coastal features that extend from beaches into bays or estuary mouths (Ciavola, 1997: 370) where the coast direction changes (Peterson *et al.,* 2008: 671). Spits can be formed naturally or artificially. Spits often have recreational value and are regarded as dynamic features that are easily disturbed by human interference (Ciavola, 1997: 370). Due to their sensitivity, management can be difficult (Ciavola, 1997: 370). Many of these coastal features have connected sand or gravel banks at the end forming a beach. Wave action and accompanying longshore transport is the most prominent coastal geomorphological process on spits and their beaches (Peterson *et al.,* 2008: 672; Jackson, 2013: 319), resulting in these beaches becoming important sediment sources or sink zones (Ciavola, 1997: 370). These beaches typically have a convex and steep profile (Ciavola, 1997: 382).

The spit at the Kromme estuary is artificial, with the sole purpose of its development being as a barrier for the canal system.

3.2.2. Coastal geomorphological processes on the peninsula

Coastal headlands and rocky shores are weakened by weathering processes (Bird, 2000: 3). The coastline is shaped by wave action and wind regime (Bird, 2000: 3). Geomorphological processes supply and remove materials from systems like coastal landscapes (Ahnert, 1994: 126). When the volume of material lost from a system over time is equivalent to the volume of material supplied to the system over the same time period, the system is in equilibrium (Ahnert, 1994: 126). Different systems have different equilibrium states, with some systems naturally not being in equilibrium (Perry, 2002: 344). A system can be in a state of dynamic or static equilibrium. A system in a static or steady state exists when there is no change to the system while processes are acting on the system. When a system is in dynamic equilibrium the processes influencing the system are self-regulating (Ahnert, 1994: 126). Negative feedback loops dominate a system in dynamic equilibrium, where the rates of the active processes influence each other (Ahnert, 1994: 126). Contemporary theories suggest that open ecological systems are non-equilibrium systems because internal and external forces drive the system (Perry, 2002: 344). Negative feedback loops influenced the peninsula prior to any development on the peninsula as the dunefields supplied sand to the beaches and wave action removed it. When there are changes to the rate of one link in the system, the system moves out of equilibrium. If contemporary theories were applied, the peninsula system was already not in equilibrium and any changes to the system amplified the non-equilibrium which resulted in prevailing disturbances or disasters.

Systems that have experienced major change become more vulnerable. Vulnerable systems are less resilient to changes, especially anthropogenic ones (Cumming *et al.*, 2005: 145). The resilience of an ecosystem is the ability of the ecosystem to absorb disturbance and maintain its present state. Ecosystem goods and services were permanently lost in systems when thresholds were surpassed and natural disasters became more frequent (Cumming *et al.*, 2005: 145). A regime shift is when an ecosystem moves from one state to another, and this shift can negatively impact the ecosystem and human system (Carpenter *et al.*, 2006: 29). When a system moves from one state to another after passing its threshold, the effects are unpredictable and the shift is permanent (Barnosky *et al.*, 2012: 52).

With the peninsula being in a state of dynamic equilibrium or non-equilibrium there was a necessity for the rates of processes to be maintained, because these systems were considered vulnerable.The Cape St Francis/St Francis Bay system was unable to maintain its state after continual anthropogenic changes and a regime shift occurred. Consequently, the beaches entered a period of erosion. Anthropogenic influences intensify shifts in regime (Carpenter *et al.*, 2006: 29).

The interactions between materials and energy shape coastal landforms (Bird, 2000: 3). The morphology of sandy beaches continually changes through wind, wave and tidal actions (Andrade and Ferreira, 2006: 995) because sand naturally moves with the waves and wind (Tunstall and Penning-Rowsell, 1998: 320). Rocky shores are more resistant to wave action (Bird, 2000: 13).

Wind and aeolian processes

Coastlines can be transformed by wind action (Bird, 2000: 23) as topography continually changes. Winds produce, direct and can strengthen waves and currents (Bird, 2000: 7, 23; Dean and Dalrymple, 2002: 4). Aeolian processes involve air moving over a surface producing lift and drag forces (Bullard, 2011: 433). If these processes become greater than those of gravity or cohesion, the surface particles will move (Bullard, 2011: 433). Aeolian processes tend to be highly variable in their direction and force. Wind erosion has a limited influence on the direction or flow of sediment because air has a low viscosity and thus is only capable of moving fine particles (Roy and Lemarre, 2011: 320). In South Africa there are landscape features that were formed as a result of wind-blown deposits or landforms (Thomas and Wiggs, 2012: 143), e.g. dunefields. Severe wind erosion takes place in coastal zones and arid regions as both geographic locations have a lack of vegetation cover to hold the soil particles in place (Roy and Lemarre, 2011: 320).

Wind was a driving process on the peninsula, transporting sand from the numerous dunefields across to the Cape St Francis and St Francis Bay beaches. While the wind regime is still acting on the peninsula, presently the process has less of an influence on beaches because the sediment load supplied is much less, due to the loss and stabilisation of many dunefields.

Wave and ocean current processes

Waves and currents affect shoreline types differently. Sand can be transported to and from beaches via waves and currents. Surface waves are especially responsible for sediment transport but waves below the surface also play a dominant role (Huntley, 2013: 40). Waves gather energy and momentum, as well as direction from wind (Dean and Dalrymple, 2002: 4). Severe storms with strong winds create big waves (Bird, 2000: 8). Storm surges are common on coastlines that experience Westerly winds that blow onshore (Bird, 2000: 9, 20). Ocean swells formed during storms have the energy to change coastline morphology (Bird, 2000: 9). These waves have the potential to erode more resistant coastal landforms and severe beach erosion typically happens during storm surges (Bird, 2000: 10). Storm surges are larger and more powerful than standard waves. Beaches try to reach equilibrium after storm events. Changes to the coastline are therefore often temporary (Reeve and Spivack, 2004: 661). Sand is transported seaward by waves reflecting off rocky shorelines (Bird, 2000: 13)

When waves break at an angle on the shoreline, carrying sand in the direction of the wave, the current is known as the longshore current (Dean and Dalrymple, 2002:8; Reeve and Spivack, 2004: 662). When the current turns seaward, sand is transported offshore. Littoral currents are formed near shorelines (Tinley, 1985: 9). The sand carried by waves and currents down the shoreline is known as littoral drift and this process of transported sand along the coast is known as longshore sediment transport (Dean and Dalrymple, 2002:8; Davidson-Arnott, 2010:11-12). Currents have an indirect influence on shaping the landscape, acting through waves (Bird, 2000: 117).

The currents passing by the two headlands of the peninsula are slowed by these landforms (Cowling, 2011: 33). St Francis Bay also experiences currents originating at the estuary mouth. The estuarine current counteracts the ocean currents and tidal actions, affecting sediment transport from these processes (Bird, 2000: 23).

Fluvial processes

Fluvial systems act as natural drainage networks that contribute to the sculpting of landscapes through the processes of erosion, transfer and deposition which forms landform features (Hattingh, 1996: 20). Their impact on land formation and development extends beyond the channel itself (Rowntree and Dollar, 2008: 53). Rivers typically comprise of erosive headwaters, partially erosive middle reaches and low-lying sink zones where eroded sediment is deposited (Hattingh, 1996: 20). In geomorphology, floods are of particular interest because of their ability to reshape the channel's morphology by transporting the eroded sediment to lower reaches of the river (Rowntree and Du Preez, 2008: 244; Rowntree, 2012: 105). Changes occur at different rates and scales in various parts of the drainage basin, which makes these systems dynamic in nature (Hattingh, 1996: 20-21). Sandy riverbeds show landform change far more frequently than bedrock or pebble riverbeds because sand is moved more easily, thus dunes in the riverbed can form, deform and reform during a single flood event (Rowntree, 2012: 95).

3.3. Coastal development

Coastal development requires the coastal zone to be in a 'stable' state in order to protect tourism and infrastructure (Tunstall and Penning-Rowsell, 1998: 320, 329). Some settlements and activities take place in areas prone to disasters and hazards while others have contributed to the increased frequency of disasters and hazards in an area (Faulkner, 2001: 135). Landforms play a fundamental role in determining the optimal site selection for settlements, structures and urban development (Verstappen, 1983: 15). The slope (inclination) of land is often considered when it comes to development, as processes like grading increase the building costs (Verstappen, 1983: 151). Four aspects often taken into account when choosing an optimal site are: the geographical location, the spatial distribution of terrain forms, the trend and aspect of relief elements (such as altitude and slope) and the size of the terrain form (Verstappen, 1983: 151). Depending on the characteristics of coastal landforms, most of the human activities that take place in coastal areas strongly revolve around tourism, agriculture and/or transportation (Özyurt and Ergin, 2010: 144). Structures are mostly built along shorelines to sustain these activities efficiently (Özyurt and Ergin, 2010: 144).

Tourism can be badly impacted by disasters and hazards. It is vital to have effective and efficient disaster and hazard management plans to support tourism (Ritchie, 2004: 673). Tourist destinations need to function optimally and mitigate any issues that arise to maintain and encourage tourist interest. Competition with other tourist destinations and the fickle nature of tourists (Peters and Weiermair, 2000: 22) means some less established destinations need to have effective disaster plans in place to avoid negative publicity. However, many areas considered to be 'high-risk' have not lost their appeal to tourists (Faulkner, 2001: 136).

Factors that attract tourists to a specific beach are the type of beach, water quality, cleanliness, accessibility, aesthetics ('natural' look), and past experiences (Tunstall and Penning-Rowsell, 1998: 322). Undeveloped coasts are attractive for being quiet and aesthetically appealing (Tunstall and Penning-Rowsell, 1998: 323). These undeveloped coasts tend to be nature conservation areas (Tunstall and Penning-Rowsell, 1998: 327). Nevertheless, developed beaches with facilities (promenades, ablutions, stores) are frequented more than undeveloped beaches (Tunstall and Penning-Rowsell, 1998: 323).

Tunstall and Penning-Rowsell (1998: 330) conducted a study in England and found beach visitors would not permit erosion of the beaches and supported coastal defence approaches. These results were compared to other studies and this perception was consistent. All studies were conducted in managed areas, which may influence the acceptance of artificial defences (Tunstall and Penning-Rowsell, 1998: 330).

In South Africa there were contradicting coastal zone boundaries prior to the Integrated Coastal Management Act (ICMA), part of the National Environmental Management Act (NEMA (Act No. 107 of 1998)) (Celliers *et al.*, 2009: 4, 5). The High-Water Mark (HWM) is a controlling factor for certain aspects of the coastal zone and is described as the furthest point the ocean reaches (Celliers *et al.*, 2009: 22). The dynamic nature of this mark means the allocated coastal zones are not always accurate (Celliers *et al.*, 2009: 22), which is why the management of the coastal zone involves both landward and seaward areas of the HWM (Clark, 1997:195). The coastal protection zone controls development at the coast (Celliers *et al.*, 2009: 23). This zone extends 100 meters inland from the HWM in urban areas and 1 000 meters inland in undeveloped (including agricultural) areas (Celliers *et al.*, 2009: 23). This Act was only implemented after much coastal development had already taken place and therefore many properties and infrastructure infringe on the coastal protection zone. Even so, when the coastal developments of the peninsula began, the distance from the HWM was greater than the distance now. The ICMA also allows for conflict between methodology choices to be resolved (Clark, 1997:198).

The Eastern Cape has a low population density but a future expectation for the coastline is increased development pressures (Knevel, 2002: 3). There has been continual coastal growth in the Eastern Cape, which has already led to the loss of numerous archeological sites (Webley and Hall, 1998:429). Coastal development includes holiday resorts, housing and places for retirement (Knevel, 2002: 3). Today the peninsula is comprised of all these developments. Anthropogenic actions are often required to maintain the state of the coast and these actions include hard and soft defence approaches (Tunstall and Penning-Rowsell, 1998: 320).

3.4. Coastal erosion

Worldwide, countries with coastlines experience coastal erosion and deposition (van Rijn, 2011: 867). Beaches are a major economic and environmental resource, specifically in areas where the strong development of coastal tourism has resulted in the major growth of several seaside resorts (Battiau-Queney *et al.*, 2003: 32) as seen on the peninsula, specifically St Francis Bay followed by The Canals, Santareme and Sea Vista. While coastal erosion is a natural process, human activities have exaggerated the process in some areas creating problems for development and infrastructure (van Rijn, 2011: 867). The resilience of coastal systems to natural change is reduced by many human processes. Human and natural processes are not independent of each other but they evolve together and in response to each other (Klein *et al.*, 1998:261). Morphological resilience of a system can be reduced when there is a loss of a sediment source to the coastal system (Klein *et al.*, 1998: 261).

In the case of St Francis Bay, the development of Santareme and stabilisation of the Oyster Bay Headland Bypass Dunefield has led to a loss of a sediment source in the system from the dunefields. The Cape St Francis/St Francis Bay system is now unable to find a state of equilibrium or return to its previous state. Ecological resilience is also dependent on the morphological resilience of the system (Klein *et al.*, 1998: 261). That is to say, if there have been changes to the morphology of the system, the 'naturalness' of the system will decrease (Klein *et al.,* 1998: 261).

To ensure socio-economic resilience in coastal systems, the shoreline tends to become a managed system, e.g. revetments for flood protection (Klein *et al.,* 1998:262). Developments in coastal areas have often lost natural flood barriers and so will rely on human-made flood barriers (Klein *et al.,* 1998: 266), e.g. beach dunes. It is important that these constructed barriers do not interfere with natural processes (Klein *et al.,* 1998: 266) but more often than not natural processes are affected. Sandy beaches are considered to be transitional ecosystems that link the land to the sea, therefore indicating a continuous flux of sand, water and biota (Fanini *et al.*, 2009: 167). A managed beach is not only characterised by artificial structures. The desire of 'clean' beaches by tourists and residents negatively impacts natural beach processes (Nordstrom, 2013: 396, 397). When wrack (seaweed, wood, vegetation) is removed from beaches the likelihood of erosion increases, as sand is not trapped by these objects, even reducing the chances of beach dunes forming (Nordstrom, 2013: 396, 397). The topography of the beaches will not experience natural changes. The wrack should rather be moved up the beaches near the foredunes to encourage growth (Nordstrom, 2013: 396, 397).

Beach erosion is an all too familiar phenomenon in France, most notably along the coast of the Atlantic (Battiau-Queney *et al*., 2003: 31). Beach erosion, and associated sand depletion, has worsened recently and is considered an economic threat especially for seaside resorts (Battiau-Queney *et al*., 2003: 31). In Wissant, North of France, there have been repeated sea-wall destructions and intermittent sand scarcity (Battiau-Queney *et al*., 2003: 31). Battiau-Queney *et al*. (2003) undertook a study that incorporated a time series analysis of aerial photographs (1947-1977) and beach surveying. The time series analysis alone provided rough estimates of shoreline deposition or erosion. The interactions between the dunes and beaches could not be accounted for with the aerial photography. Therefore beach surveys were conducted using a differential GPS (DGPS) from the toe of the fore dunes to the low tide mark to test the accuracy of the estimates and gain a more holistic view of the system dynamics. The surveys revealed that backwash processes are present on the beach and responsible for fore dune and upper beach changes, with the most strength seen in storm conditions.

The Cape St Francis/St Francis Bay peninsula has been fighting coastal erosion for many years. In 2011 an article in the newspaper *Our Times* stated there had been a 35 meters beach recession in some beach sections in St Francis Bay between 2001 and 2011. This is dramatically higher than the seven meter recession estimated between 1940 and 1970. An outline of the Kouga Municipality budget was given: R95 000 was set for sand pumping, R250 000 was set to safeguard existing assets (roads, parking lots) and R250 000 was set to complete an EIA.

3.4.1. Monitoring coastal erosion

Coastline changes can be assessed over long and short temporal scales when historical images and maps are compared to more recent images (Bird, 2000: 4). Due to the dynamic nature of beaches, it is also necessary to monitor the shoreline and beach features (e.g. width, beach dunes) over time (Baptista *et al.*, 2008: 1516). As a result of widespread development, the resilience of many ecosystems is directly linked to its management. The ecosystem changes are gradational, with some changes being predictable with low magnitude and other changes being unpredictable with higher magnitudes (Carpenter *et al.*, 2006: 29). Predictable changes can be mitigated with intervention methods. Unpredictable changes and those with higher magnitude are difficult to mitigate and intervention methods can be costly (Carpenter *et al.*, 2006: 29). In some instances, mitigation is impossible. Along with aerial photography, field measurements can aid coastline change assessments. For accurate estimates of sand movement, field measurements are necessary (da Silva *et al*., 2006:898). Monitoring can include noting shoreline and geomorphic feature changes, allowing short-term patterns to be identified (Morton *et al*., 1993:702).

Management of the peninsula is difficult because of the different management plans and management areas run by different organisations (La Cock and Burkinshaw, 1996: 378). These different plans and managing organisations severely hinder the conservation of the Sand River and the Oyster Bay Headland Bypass Dunefield (La Cock and Burkinshaw, 1996: 380). Cooperative and adaptive governance combined with scientific information helps to ensure management success (Celliers *et al.*, 2009: 2). The decision making process must involve local government and interested parties (Celliers *et al.*, 2009: 2). The involvement of the public is important if management is to be successful.

3.4.2. Coastal defence approaches

From 1960 to present day the frequency of natural disasters has quadrupled, affecting more than one million people (Carpenter *et al.*, 2006: 29). As the population increases, the frequency of these events is expected to rise as well (Carpenter *et al.,* 2006: 29). Beach erosion has become a more threatening and prominent issue and so beach protection is gaining more interest (Whitehead et *al.*, 2008: 2).

The typical reaction process of an individual and community affected by natural disasters is described by Booth (1993: 102, 103): (1) the individual and community are in a state of shock after a natural disaster, (2) the individual and community are in denial that the problem is severe or there is an exodus from the area, (3) the individual and community acknowledge the problem is severe and (4) adaption is necessary. Adaptation can be realised through protective measures where prevention is the focus of the measures, or through the accommodation of disasters into everyday life where changes are made to the human system, or the settlement moves to another area. In some cases communities will do nothing (Gunderson, 2000: 432).

The peninsula residents have responded with protective measures by constructing revetments along the beaches in St Francis Bay as well as slightly altering the golf courses so that flood waters can flow to the sea with little infrastructural damage.

Defence structures and approaches are separated into hard and soft. Hard defence approaches require ‘hard’ structures to be constructed, for example groynes, revetments, and seawalls. These structures have been constructed across the world to combat beach erosion (da Silva, *et al.*, 2006: 897; Fanini *et al.*, 2009: 167). Soft defence approaches include beach nourishment where sand is pumped onto beaches to increase beach width. This approach is considered the most environmentally friendly and ‘natural’ answer to the erosion problem because it only needs to displace material instead of requiring construction and it is therefore increasing in popularity (da Silva *et al.*, 2006: 897; Jakobsen and Brøgger, 2007: 1; Fanini *et al.,* 2009: 168). Soft defence approaches, while expensive (Jakobsen and Brøgger, 2007: 1), are currently the most accepted and advised coastal defence approaches in contemporary literature (Tunstall and Penning-Rowsell, 1998: 320).

Despite the ‘natural’ look of a beach being an attractive quality, Tunstall and Penning-Rowsell (1998: 330) found that beach visitors would rather see hard structures than allow erosion (Tunstall and Penning-Rowsell, 1998: 330). An example of this was at Hengistbury Head, England, where five groynes were constructed with public support in an attempt to reduce erosion (Tunstall and Penning-Rowsell, 1998: 330). The perception of ‘letting nature take its course’ was not unanimous with beach visitors and development owners (Tunstall and Penning-Rowsell, 1998: 330). In the Netherlands there was unanimous support for coastal defences in 1989-1990 (Tunstall and Penning-Rowsell, 1998: 330).

In South Africa, a harbour engineer from East London designed the coastal defence structure 'dolosse', which are concrete blocks with branches (Fulton, 2006). The blocks intertwine to create a strong defence wall that moves with wave action (Invent Africa, 2013). The design was not patented and so was implemented around the world (Fulton, 2006) within 10 years (Invent Africa, 2013). Dolosse are placed in many ports around South Africa (Invent Africa, 2013) and along the N2 in Port Elizabeth (Fulton, 2006). Typical coastal defence structures include revetments and sea walls but multiple approaches are used when coastal erosion is severe, which is typical in highly developed areas (James and Hermes, 2011: 96). In KwaZulu-Natal (Durban) numerous coastal defence methods have been implemented and installed, which include a combination of hard and soft coastal defence methods (Breetke and Mather, 2013: 1). The history of Durban's beach protection efforts are directly related to the development of the port (Corbella and Stretch, 2012b: 121). The city constructed a mound and an unsuccessful groyne field (Corbella and Stretch, 2012b: 121). A new groyne field and a permanent sand bypass scheme were then constructed and this successfully stabilised the beaches (Corbella and Stretch, 2012b: 121). Durban also installed 20 000 sandbags in seawalls between 2007 and 2011 due to the severity of coastal erosion in the area (Corbella and Stretch, 2012b: 121). The city has, therefore, gained experience in coastal defence systems (Corbella and Stretch, 2012b: 121). A guide published in 2008 (*Living with Coastal Erosion*) by the KwaZulu-Natal Department of Agriculture and Environmental Affairs highlighted the significance of combining the various coastal mitigation techniques and schemes as discussed, even describing shoreline retreat (removal or relocation of houses and infrastructure) (Breetzke and Mather, 2013: 1). The recommended strategy was to work together with the natural processes in response to erosion (Breetzke and Mather, 2013: 1). The creation of the berm (consisting of geotextile sandbags) proved particularly successful. The berm height had to be that of the original dune and was covered with sand and appropriate vegetation (dune species) (Breetzke and Mather, 2013: 1). The toe of the berm was further protected through gabion baskets filled with bags. The method was concluded as cost-effective and the outcomes were remarkable through the improved slope stability, reduced wave energy and allowing for natural processes to take its course (Breetzke and Mather, 2013: 1). A good monitoring system was considered essential for effective management of coastal areas (Corbella and Stretch, 2012a: 64).

There was speculation that revetments and seawalls increase beach erosion instead of preventing it. It was suggested by Anderson (2008: 2) that these structures are referred to as 'land protection structures'. Fletcher *et al.* (1997: 212) explained that erosion in areas upland of these structures is lessened, but these areas were then excluded from the littoral sediment budget. This loss of a sediment source was the cause of the erosion and narrowing of areas downdrift of the structures (Fletcher *et al.,* 1997: 212).

Fanini *et al.* (2009) conducted a study in San Rossore-Migliarino-Massaciuccoli Regional Park, Italy, assessing the beach changes in response to groynes and beach nourishment. The Park beach was divided into eight segments as a result of the construction of nine groynes along the beach. Each segment had its own ecological characteristics (Fanini et al., 2009: 175) due to differences in the groynes' interaction with waves and associated currents (Fanini et al., 2009: 168). It was found that groynes became ecological barriers (Fanini et al., 2009: 175). The segments selected for beach nourishment were the two beaches closest to the river mouth (where the available sand was) and where erosion was believed to be the most severe. The defence approaches proved effective, as there was an increase in beach width and a decrease in beach slope (Fanini et al., 2009: 170).

The Spurn Head spit, England, has been heavily impacted on by anthropogenic actions like jetty and groyne construction (Ciavola, 1997: 385, 388). The beach width increased downdrift of the groynes; however, they were considered non-beneficial to the total longshore budget as the available sand for the transportation around the tip of the spit had already been diminished (Ciavola, 1997: 385). However the seawall constructed in the center of the spit prevented it from migrating westerly. Jetties also impacted the mobility of sand on the mid- and upper parts of the beach (Ciavola, 1997: 385). The groynes had a negative effect on the net longshore drift into the Brink reservoir and have been destroyed by sea-action, resulting in beach erosion (Ciavola, 1997: 388). The seawall has held the shoreline in an unnatural position and soon after the wall collapses over wash will occur (Ciavola, 1997: 388).

North Carolina altered legislation disallowing hard structures along the coastline, promoting the implementation of the soft defence of beach nourishment (Whitehead *et al.,* 2008: 2). The beach nourishment project will run for 50 years with nourishment occurring every 3 to 5 years (Whitehead *et al.,* 2008: 10). Through interviews Whitehead *et al.,* (2008: 10) found that while there was not unanimous support for this change most participants believe the method will be effective (Whitehead *et al.*, 2008: 10).

Another soft approach for beach stabilisation is known as beach dewatering, where water is drained from beaches to allow for infiltration and reduced backwash (Walstra *et al*., 2014: 1). Yet many studies were unable to distinguish between natural beach changes and those induced by active dewatering systems (Walstra *et al*., 2014: 1). Pressure Equalisation Modules (PEM) were regarded as a passive drainage system (Walstra *et al*., 2014: 1), and was considered to be a new, cost-effective and environmentally friendly soft defence mechanism solution (Jakobsen and Brøgger, 2007: 1). In comparison, dredging was a common method used for nourishment projects and deemed to be costly and ineffective in the long-term as sand generally disappears after the first spring high tide (Jakobsen and Brøgger, 2007: 1). The vertically installed PEM pipes consisted of 1 meter filter tubes combined with a 0.75 meter steel tube on the bottom and a ventilation filter cap on the top (Jakobsen and Brøgger, 2007: 3).

This alternative beach nourishment project reached popularity in Denmark where experiments were completed along the west coast (Jakobsen and Brøgger, 2007: 1). PEM tubes were placed between the survey lines at 100 meter intervals in length and every ten meters in cross sections (Jakobsen and Brøgger, 2007: 3, Walstra *et al*., 2014: 2) covering the total length and width of the beach. The width of the beach is situated between the high water and low water mark (Walstra *et al*., 2014: 2). Knowledge of water level and weather conditions (e.g. wind) is needed and an average beach level needs to be established as it was considered an important parameter (Jakobsen and Brøgger, 2007: 5). Beach level was established through GPS surveys (less than 2 cm elevation tolerance) (Jakobsen and Brøgger, 2007: 3) which were conducted prior, during and after the PEM-system installation for temporal change comparison purposes of the near shore morphology and then compared to a reference site (Walstra *et al*., 2014: 1).

In Denmark, along the west coast, the PEM system and surveys were done quarterly and the system was deemed successful as it raised the beach level (Jakobsen and Brøgger, 2007: 3). The accumulation of sand was more than 50% higher than in relation to the surveyed sites (Reference 1 and 2), there was no leeside erosion (only accumulation), no steepening of sea bed, normal erosion stopped by two meters in elevation per year and the effectiveness of the

SIC vertical drainage system amounted to more than 800 000 m^3 in just one year (Jakobsen and Brøgger, 2007: 6, 7).

In comparison, the installation of the PEM-system on the south coast of Egmond (The Netherlands) over a four-year surveying period showed a less discernible result as the test and reference site showed similar patterns (Walstra *et al*., 2014: 11). It is believed that PEMs are only classified as effective if the reference site benefitted significantly more than the test area (Walstra *et al*., 2014: 11). In the Netherlands the PEM-system was believed to have not worked and there are numerous constraints for future applications which include: no proof of the study working, no theoretical placement guidelines for vertical PEM pipes, and beach-dune morpholocial changes in natural settings cannot be linked to PEM pipes (Walstra *et al*., 2014: 14). The efficacy of the PEM-system will have to be identified in future experiments, as beach drainage systems as so far have low success rate (Walstra *et al*., 2014: 1).

The PEM-system was installed in 2007 on the spit and St Francis Bay beaches in an attempt to lessen erosion. In 2013 the system was abandoned.

Through beach nourishment, natural processes can recommence on the beach (Nordstrom, 2013: 398). Topography changed with some beach dunes forming and deforming. The resuming of natural processes depended on the nourishment frequency and so these projects needed to be on a large-scale (Nordstrom, 2013: 398). Alternatively, there could be higher nourishment frequency over a smaller area. The role of active processes changed as the nourishment results in an imbalance of landforms shaped by the wind regime and wave actions, therefore these projects need to be on a large-scale (Nordstrom, 2013: 399). Aeolian processes and effects were changed when the upper beach received nourishment (Nordstrom, 2013: 399). Dunes can be formed or present dunes nourished. For beach nourishment to be successful beach dynamics need to be understood, as deposition may occur naturally, or the beach may experience cyclical changes of erosion and deposition (Stive *et al.*, 2002: 211). Beach nourishment was ideal for coasts where the sea level is rising (van Rijn, 2011: 868).

A critical issue revolving around the implementation of defence structures in an area is the implementation cost. The available funds dictate the amount of sediment pumped onto a beach (Nordstrom, 2013: 398). In the United States, the state and coastal communities contribute to payment of defences (35 % provided by communities and 65 % provided by the state) (Whitehead *et al*., 2008: 2).

The management costs of the peninsula are expected to be covered by the residents. An alternative suggestion is that the municipality should pay and the residents will slowly pay back some of the cost through increased taxes and rates (La Cock and Burkinshaw, 1996: 379). An EIA was conducted in St Francis Bay to find solutions to the beach erosion issue, and the suggested solutions included groynes and artificial reefs as well as beach nourishment (Municipal document, 2007: 1). These solutions could not be implemented because of the limited funding available in the Kouga Municipality budget (Municipal document, 2007: 1). Consequently a proposal was made to the Provincial and National Governments for disaster relief funding (Municipal document, 2007: 1).

3.5. DPSIR framework

Literature has acknowledged the link between social and ecological systems but previously less attention was given to measuring and understanding the importance and degree of the interactions involved between the systems (Bowen and Riley, 2003: 299). Management of these systems, encouraged through protocols like the Millennium Ecosystem Assessment, required information on the dynamics between the systems and so the importance and degree of the interactions became more documented (Bowen and Riley, 2003: 300). The Integrated Coastal Management (ICM) approach must have structure and be replicable globally for coastlines around the world to be managed effectively (Bowen and Riley, 2003: 300). It is important to have local stakeholders involved in the approach and for them to benefit from it (Bowen and Riley, 2003: 300). In many ICM programs there are goals outlined, which promoted an improved environment state, but the methods to achieve the goals are unspecific and undetailed due to a lack of system understanding (Bowen and Riley, 2003: 303). The workings within the community, in combination with the capabilities of associated institutions and their policies, influence the ICM approach to be implemented in an area (Bowen and Riley, 2003: 303). Bowen and Riley (2003) and Sekovski *et al.* (2012) promote a general framework, where the aforementioned approach requirements could be met, based on previous literature such as the Organisation for Economic Cooperation and Development (OECD) 1993 ‘Pressure-State-Response’ (PSR) model, the United Nations Commission on Sustainable Development ‘Driving Force-State-Response’ (DFSR) model, and the most refined ‘Driver-Pressure-State-Impact-Response’ (DPSIR) model. The DPSIR framework model was used in a South African scenario through which two municipalities of the Eastern Cape were chosen based on their physical and environmental characteristics (similarities)

(Palmer *et al*., 2011:159). Despite this similarity distinctive differences could be seen with regards to development and land use change (Palmer *et al*., 2011: 171). Through the use of the framework sensitive or vulnerable sites could be brought to light, which would encourage the conservation of coastal areas (Palmer *et al*., 2011: 172).

Limitations with the PSR model were the lack of inclusion of natural events into the pressure category and over simplicity of the system (Bowen and Riley, 2003: 305). The DFSR model has its own limitations where reasoning behind pressures and response actions is not given (Bowen and Riley, 2003: 305). It is important that there is continual transdisciplinary work between social and natural scientists for models to be effective (Turner, 2000: 22). The DPSIR is a more encompassing model where the socio-economic sphere is included in the *drivers* category (e.g. changes in land cover and use), negative human actions in the system are included in the *pressures* category (e.g. using fertilisers on farms and home gardens), changes in the environment fall into the *state indicators* (e.g. changes in water quality) changes to the socio-economic sphere as a result of the environment changing are described in the *impacts* category (e.g. lower fishing yields as a result of poor water quality), and mitigation actions are included in the *response* category (e.g. controlled amounts of fertilizer used) (Bowen and Riley, 2003: 306) (Figure 6). This model effectively incorporates the socio-economic systems with ecological systems (Turner, 2000: 10, 11; Bowen and Riley, 2003: 308; Sekovski *et al*., 2012: 49).

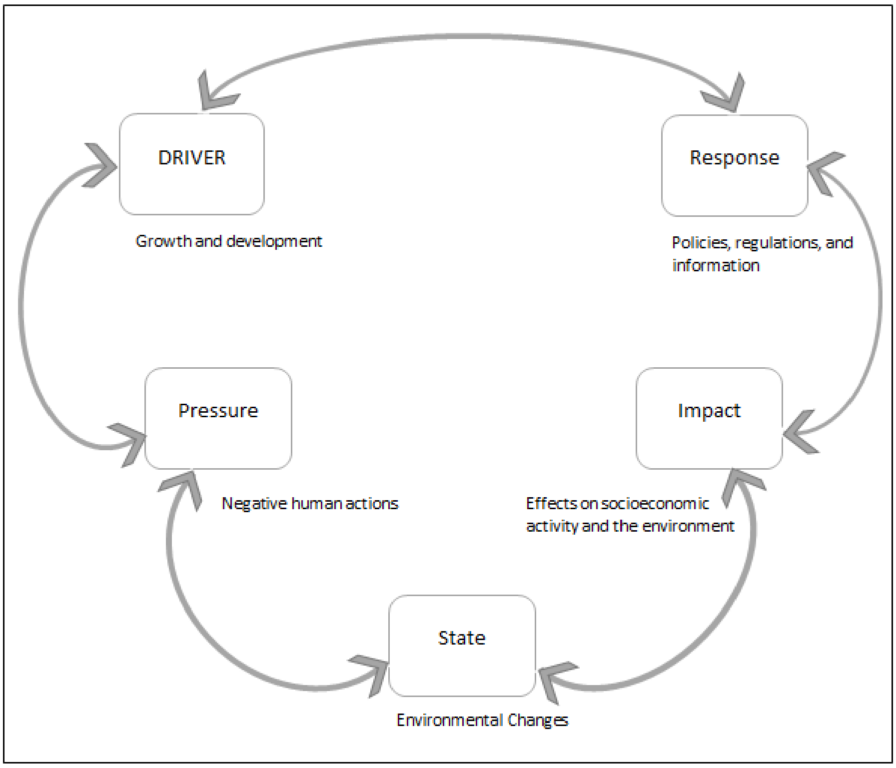


Figure 6: DPSIR Framework (adapted from Bowen and Riley, 2003: 306)

3.6. Key studies of the peninsula

The peninsula has been a popular study area for research because of the dynamics and multiple aspects and processes influencing the natural and human landscapes. These studies have pursued different research topics focussing on particular features or processes.

3.6.1. Beach erosion

Lubke, 1985: Erosion of the beach at St Francis Bay, Eastern Cape, South Africa.

The focus of this article was to show erosion survey results, explain changes to the St Francis Bay beach and provide solutions. The peninsula's residents had expressed concern about sand erosion from the St Francis Bay's main beach and the effect this would have on the value of the peninsula's properties in the long term. The entire Santareme development and most of the St Francis Bay development were built on stabilized driftsands. The alien invasive species *Acacia cyclops*, locally known as Rooikrans, was mostly used to stabilise the dunefield. Stabilised dunes became susceptible to erosion with higher sea levels, which threaten beachfront properties and the St Francis Bay Hotel. Vegetation surveys on the beach were first undertaken in 1975 and resurveyed in 1982. The key finding of the vegetation surveys was a significant decrease in vegetation abundance and frequency from 1975 - 1982. Beach surveys were also conducted where the high water mark was recorded and the sand volume was calculated. The proposed source of sand for the beach was the Oyster Bay Headland Bypass Dunefield. The key finding of the beach surveys was a nine meter beach recession over the same period. To avoid further beach loss, it was suggested that there be a continuous supply of sand delivered to the beaches and alien invasive species removed. Another suggestion was to include Second Bush Beach (the Port) as part of the Cape St Francis Nature Reserve. When enough sand has aggraded on the beaches, dunes can be stabilized with indigenous plant species.

McLachlan et al., 1994: Management implications of tampering with littoral sand sources

The study compared aerial photographs of the Cape St Francis/St Francis Bay peninsula and determined a static beach period between 1942 and 1975. The Santareme Dunefield is believed to have been stabilised in 1964. An estimated nine meter beach recession occurred during 1975 – 1982. In 1978 the peninsula experienced a major erosive storm resulting in noticeable beach recession. The authors concluded that the stabilisation of Santareme and Oyster Bay Headland Bypass Dunefield incited beach change as Santareme alone contributed approximately 91 000 m^3 of sand annually (McLachlan *et al.*, 1994: 57). The Shark Point Dunefield is still active and supplies a mere 7 000 m^3 of sand annually comparatively (McLachlan *et al.*, 1994: 57). The decrease in supply has led to coastal erosion.

Municipal document, 2007: St Francis Bay beach erosion disaster

The document is an application for Disaster Relief Funding. Beach erosion was highlighted by the documentation of erosion events and calculations of sand loss and beach width. 2005 saw a 20 metre beach recession in three months. In less than one year (August 2006 – March 2007) 110 000 m^3 of sand was lost from the St Francis Bay beach and beach dunes. The greatest recession was 16 meters and infrastructure damage was seen along the beach. The spit was severely eroded during this time, losing an estimated 33 % of beach and dune sand. Relief effects included placing 960 m^3 of rocks and 12 000 m^3 of soil alongside affected infrastructure and on beaches. The peninsula is quite reliant on tourism and with the continual erosion fewer tourists visited the area in December 2006. Property prices are also decreasing in an attempt to encourage continued investment.

Anderson, 2008: A hybrid approach to beach erosion mitigation and amenity enhancement, St Francis Bay, South Africa.

The focus of the thesis was to examine the Cape St Francis/St Francis Bay peninsula environment and find possible solutions to the beach erosion problem. The Oyster Bay Headland Bypass Dunefield was a major source for beach nourishment, providing an estimated 80 % of the total sand supply. Key findings included a significant quantity of sand lost. This was seen through bathymetric survey comparisons and a 40 000 m^3 sand loss from September 2006 to September 2007. South-easterly waves are erosive. Proposed solutions included removing alien invasive species and using indigenous species to rehabilitate dunes, beach nourishment and the construction of an artificial reef. The best solution is believed to be detached breakwaters.

3.6.2. Peninsula dunes

Tinley, 1985: Coastal Dunes of South Africa

The focus of this report was to provide information on coastal dunes in South Africa. The processes behind the formation and erosion of coastal dunefields were highlighted. Development needs tended to outweigh ecological needs and so sustainable development recommendations were given. Plans for conserving, recovering and managing dunefields were presented. Soft coastlines (as is the case on the Cape St Francis/St Francis Bay peninsula) were prone to erosion when sand in the active zone was lost. The time taken for erosion to take place after sources are loss was quick. The movement of sand from dunes to beaches was a natural process of coastal protection.

La Cock and Burkinshaw, 1996: Management implications of development resulting in disruption of a headland bypass dunefield and its associated river, Cape St Francis, South Africa.

The article focused on the functioning and disturbance of the Sand River and the Oyster Bay Headland Bypass Dunefield, as well as potential solutions. The Sand River was a distinctive feature to the Oyster Bay Headland Bypass Dunefield. When the Sand River drains the dunefield and floods, sand was deposited in the Kromme River, forming a delta. The natural functioning of the Sand and Kromme Rivers was disrupted through development. The Santareme development amplified St Francis Bay beach erosion. One limitation to management of natural systems is the different landowners on the peninsula. The cooperation of conservationists and developers is imperative.

Lubke and De Moor, 1998: Field guide to the Eastern and Southern Cape coasts.

The focus of the book was to provide information on the eastern and southern coastlines of South Africa. The information included ecological, zoological and human influences along the coastlines. A higher sea level due to loss of sand on beaches was experienced in St Francis Bay. The reason given for this reduced beach width was the stabilization of driftsands with alien invasive plant species that spread rapidly. The St Francis Bay development was described as ‘inappropriate’ (pg. 453). In St Francis Bay, sand was pumped onto beaches in an attempt to lessen erosion. Archaeological sites were lost through developments like Cape St Francis. In South Africa, the Oyster Bay Headland Bypass Dunefield is the best example of a functioning system of this kind. However, the source of sand for the dunefield had been isolated and so functioning has decreased. Rough seas are often experienced at Cape St Francis. Coastlines to the east of the Cape St Francis headland had sand deposited on the shores. This sand was eroded from the headland. Ecological functioning and processes need to be understood prior to development to avoid expensive solutions.

Illenberger and Burkinshaw, 2008: Coastal dunes and dunefields.

The Oyster Bay Headland Bypass Dunefield is still active and covers 18 km. Sand was transported from west to east across the headland bypass dunefield. The Westerlies promote dune formation on the peninsula. The Easterlies counteracted the effects of the Westerlies. A key finding approximated annual aeolian transport contribution at 9 000 m^3.

*Elkington, 2012: Morphology, patterns and processes in the Oyster Bay Headland Bypass Dunefield, South Africa***.**

The focus of the thesis was the interaction between ground- and surface water as transporters of sediment in the dunefield, and to better understand the system dynamics. The role of water as a driver of sediment flux in the dunefield had been overlooked in most other literature on the dunefield. The study found that dunefield dynamics differed on either side of the crest: sediment flux in the dune area west of the crest was found to be driven by wind action, while sediment flux east of the crest was found to be driven by water, as seen through floods and debris flows. The study gave a deeper understanding of processes influencing the dunefield. Elkington (2012) called for better understanding of the dunefield by further investigation of the role of water in the system.

3.6.3. Sand River

Schroeder, 2012: Bedload sediment fluxes along the Sand River, Oyster Bay Headland Bypass Dunefield: Implications for sediment delivery to St Francis Bay.

The thesis focused on the role of the Sand River in sediment transportation from the dune crest to the Kromme River. The study followed on from Burkinshaw (1998) and Elkington (2012) providing insight into the fluvial component of the Oyster Bay Headland Bypass Dunefield. The Sand River drains a small catchment of the dunefield and is often perceived as an insignificant stream which has no or low flow (Figure 7A). A key finding was the Sand River played an important role in large sediment fluxes which have occurred following prolonged rainfall periods (Figure 7B). Through this process the riverbed morphology experienced seasonal changes (Figure 8).

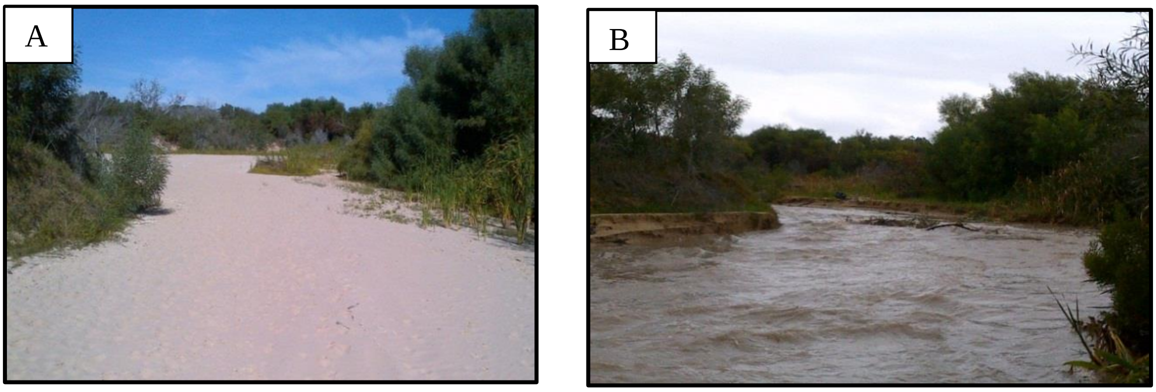


Figure 7: The Sand River during no flow on 17 May 2012 [A]; and after prolonged rainfall period during high flow 8th August 2012 [B]

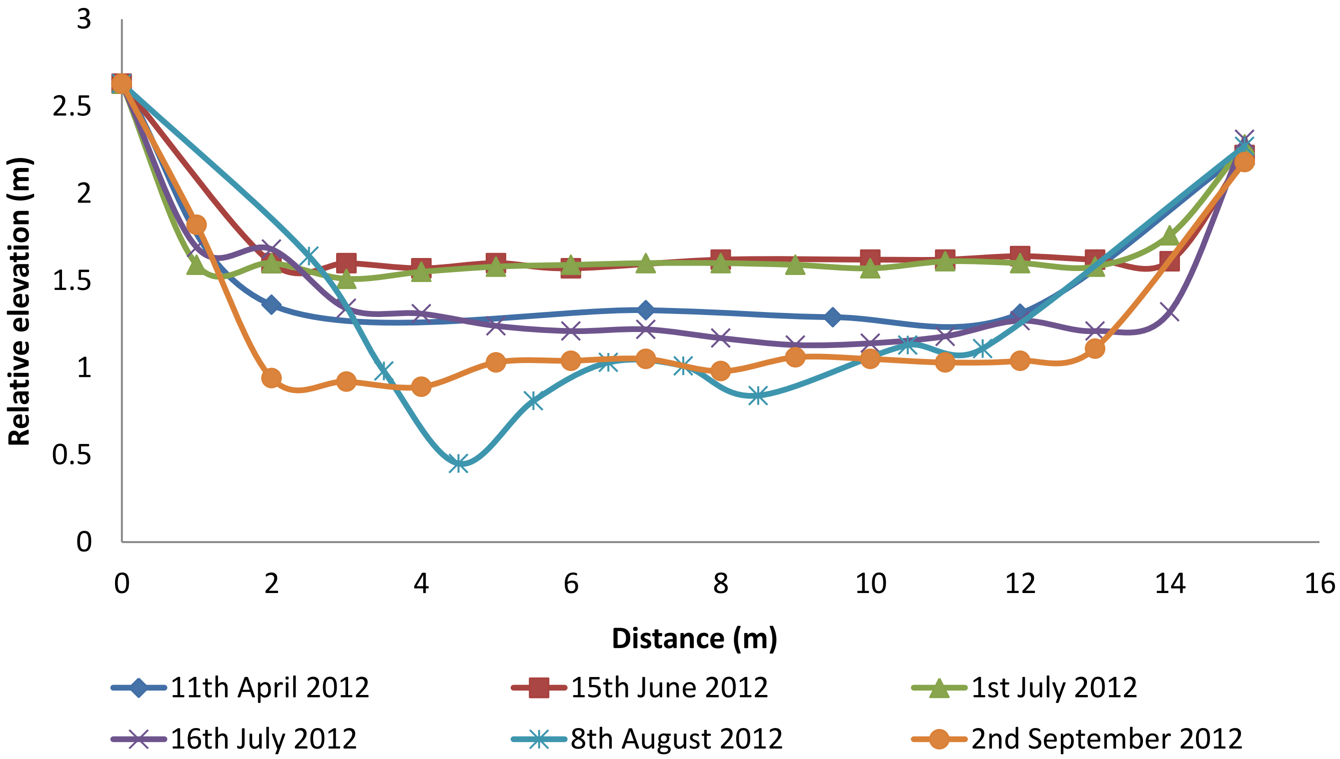


Figure 8: Seasonal riverbed morphological changes of the Sand River (2012)

3.6.4. Wetlands

Rebelo et al., 2013: Are we destroying our insurance policy? The effects of alien invasion and subsequent restoration: A case study of the Kromme River

The focus of the thesis was to assess land cover changes over 50 years and the associated hydrological effects in the Kromme River catchment. Key findings included major changes to catchment wetlands, which increased susceptibility of the catchment to flooding. If restoration plans are followed the river catchment ecosystem services will improve. Wetland restoration will improve river water quality and flood defences. The flow of the Kromme River will improve when alien invasive plant species are removed.

3.7. Assessing coastal geomorphology

3.7.1. GIS in geomorphology

"The mapping of landforms is probably as old as the making of maps" (Smith and Pain, 2011: 142), and thus, through the compilation of required information on maps and interpreting the spatial patterns, relationships can be depicted and a broader picture of the complex system can be formed (Vitek *et al.*, 1996: 233). Geographic data can now be visually displayed through the robust methods and processes of cartography (Dodge *et al.*, 2011: 289). Maps, particularly topographic maps (1: 50 000), are an integral component of geomorphological research (Vitek *et al.*, 1996: 233).

Geographic Information Systems (GIS) and remote sensing (RS) allows for an advanced methodology to be applied while developing new algorithms to accurately identify, delineate and classify these landforms together with their processes (Vitek *et al.*, 1996: 233). Innovations in GIS and RS have led to improvements in the geomorphology field but these methods can be used individually (Walsh *et al.*, 1998: 184). Examples of landscape analysis include watersheds, land cover type, and elevation models (Walsh *et al.*, 1998: 184). Landscape indicators such as vegetation and climatic conditions are used to make assumptions about geomorphic processes acting on the landscape (Walsh *et al.*, 1998: 186).

The evolution of the coastline and its features can be seen through aerial photographs. GIS integrates data in an illustrative and versatile approach (data capture, management, storage, display, analysis, and retrieval) (Walsh *et al.*, 1998: 184). This allows data to be displayed in a way that highlights less obvious dimensions (Hall *et al.*, 2009: 2055). Remote sensing (RS) involves landscape assessments on local and global scales through images and sensor systems (Walsh *et al.*, 1998: 184). Remote sensing, specifically the use of aerial photography, is commonly used in coastal studies where shorelines are mapped over time (O'Regan, 1996:193). This is why visual representations are considered a vital component of geomorphological studies: they visually present spatial and temporal distributions of phenomena's which often provide clues in identifying processes that generate them (Vitek *et al.*, 1996: 233).

Time series methodology

Aerial photography is considered an essential data source in determining and understanding changes over time (Barrette *et al.*, 2000: 409). Aerial photography is thus a suitable data source for monitoring landscape changes (Mulkova and Popelkova, 2010: 401). Orthophotographs can also be used as they have been geospatially referenced – meaning that they have scale accuracy across the entire image (Barrette *et al.*, 2000: 409). A time series can be created with aerial photography showing temporal changes of the landscape (Walsh *et al.,* 1998: 186, 191). Temporal and spatial changes and patterns can be seen concurrently when looking at a time series (Dodge *et al.,* 2011: 234). This approach has one dimension in that it moves linearly as past events are connected to the present and can influence the future (Longley *et al.*, 2005: 87). However, interpretation of the spatial changes over the time series is two dimensional, sometimes three dimensional (Longley *et al.,* 2005: 87). Different image types have different time spans, e.g. Landsat Thematic Mapper spans 15 years and Landsat Multispectral Scanner spans 25 years (Walsh *et al.,* 1998: 186). Different image types also have different resolutions and landscape coverage, e.g. Landsat images have better coverage and SPOT MX images have better resolution (Li *et al.* 2001:17). Nevertheless it is important to incorporate field techniques with GIS and RS analysis (Walsh *et al.,* 1998: 184).

Boeyinga *et al.* (2010) used aerial photographs to assess the migration of the Santinho Dunefield in Santa Catarina State, Brazil, and the Mocambique Dunefield on the Santa Catarina Island from 1938 to 2007. Measuring the movement of the dune crests between 1978 and 2005 showed the Mocambique Dunefield migrated at an average rate of 3.75 meters annually. This rate was applied to the Santinho Dunefield as dune crests could not be distinctly identified.

3.7.2. Interviews

Experts coming to an area do not always see all the landscape benefits and the interactions between them, making local knowledge invaluable in many cases (Fagerholm *et al.,* 2012: 422). Involvement of local stakeholders is essential to create a holistic view of the peninsula. To include a qualitative approach in research, interviews can be conducted. Interviews based on mapping the area contribute qualitative and quantitative data to research. Interview research has often followed the 'snowball sampling' method (Biernacki and Waldorf, 1981: 141, Teddlie and Tashakkori, 2009: 175) (Figure 10). When this method is implemented early in the study, the scope can be established (Morse and Niehaus, 2009: 65). Goodman (1961: 148) explains snowball sampling as selecting a group of individuals who refer the interviewer to other individuals who provide further referrals. The group of interviewees broadens randomly, encompassing more views. Different interviewees have different specified interests which allow the interviewer to have more in-depth understanding of a topic. The interviewer needs to continually be proactive in the process (Biernacki and Waldorf, 1981: 143) and a concerted effort must be made to interview a diverse group of people (Morse and Niehaus, 2009:65). This approach is beneficial when the interviewer does not know which individuals are knowledgeable in the area (Morse and Niehaus, 2009: 65). The type of information received from stakeholders can be influenced by their personal relationships with each other (Castella *et al.*, 2007: 543), e.g. shared biases or bias against each other. Another interview method is the convenience sampling method. This method involves the interviewer publicising the study to attract participants and they then interview all or selected individuals who meet the prescribed criteria (Morse and Niehaus, 2009: 64).

Interviews can have different structures depending on the desired outcome. Morse and Niehaus (2009: 128-130) and Schutt (2009: 283, 284) describe questionnaire structures applicable to this study: semi-structured interviews, guided interviews and open-ended unstructured interviews. Interviewers who have enough knowledge on the subject use semi-structured interviews. These interviews have set questions but the interviewer cannot foresee all responses. The order of the questions asked is maintained for all interviewees and all the same questions are asked. The interviewer may ask for further explanations of answers if necessary. During guided interviews there are prepared questions but not all question need to be asked or follow the same order, allowing the interviewee some control over the direction of the interview. The interviewer maintains control of the flow and length of the interview. An open-ended unstructured interview is controlled by the interviewees, enabling them to share their views and stories while the interviewer listens. These interviews are often conducted in a comfortable and trusting space for the interviewee.

Interviews can be conducted over the telephone or in person. Telephone interviews need structure so that the interviews are not time-consuming (Schutt, 2009: 283). The most successful interviews are done in person because a response is certain, compared to telephone and email interviews where participants may not respond (Schutt, 2009: 283). In an interview questions can be more in depth and the interview longer, as questions can be clarified and answers elucidated on (Schutt, 2009: 283). Random sampling is preferred over convenience sampling because a representative sample is obtained (Creswell, 2003: 156). The chances of individuals being selected for the study with random sampling are almost equal (Creswell, 2003: 156). With convenience sampling, individuals are selected because of their availability and ease of access (Creswell, 2003: 156). Advantages of including interviews in research are that the interviewer has control over and historical information about the area can be obtained from the interviewees (Creswell, 2003: 186, 187).

Background morphological information can also be gained through old photographs (Boak and Turner, 2005: 697). Photographs are discrete and visually illustrate how an area used to be (Creswell, 2003: 186,187). It must be noted that other than the observations made from the photographs, there is little other information obtained, e.g. tide or scale (Boak and Turner, 2005: 697). Therefore, the photographs have a more qualitative value (Boak and Turner, 2005: 697). Documents and newspapers are also sources of historical information captured over many years (Creswell, 2003: 186, 187). However their accuracy can be questionable and documents may be subjective (Creswell, 2003: 186, 187). Some information may be incomplete or protected (Creswell, 2003: 186, 187).

There are ethical considerations that must be followed while conducting interviews. Five important ethical considerations that will be followed in this study are stated by Creswell (2003: 64-65) and are as follows: (1) the interviewee has the choice to take part in the study or not to, and is able to leave when desired, (2) the purpose and intention of the study are explained to and understood by the interviewee, (3) the interviewee knows what will be required of them to some degree, (4) the privacy of the interviewee is respected and they are allowed to ask their own questions and (5) the results of the study may be shared with the interviewee if so desired; the interviewee will benefit from the study.

In this study individuals from different suburbs and races were interviewed. A combination of these discussed methods will provide a broad view of the present and past state of the peninsula as well as the perceived future.

Despite the incorporation of local knowledge into scientific research being uncommon (Aswani and Lauer, 2006: 66), the method used for this study aims to produce an expert ‘local’ map of the Cape St Francis/St Francis Bay peninsula. This allows the local communities, residents and members to get involved, a strategy positively enforced by

Aswani and Lauer (2006: 65, 66) where the authors state that the use of local expert knowledge is a cost-effective data collection method. Local stakeholders mapped features that are perceived to be hazards and where resulting natural disasters have happened on the peninsula. This attempts to highlight which landforms and processes are prominent on the peninsula. A time frame of when the disaster happened was provided where possible.

In recent years there has been a realisation that traditional science has limitations, particularly in its ability to deal with behavioural aspects (Hall *et al.,* 2009: 2055). It is for this reason that the incorporation of traditional or local knowledge was of interest. This did not represent a paradigmatic shift, but rather a broadening of the conceptualisation of the knowledge base. Knowledge of those who have worked with a given resource or lived in a certain area over multiple generations were accorded equal footing within scientific analysis (Hall *et al.,* 2009: 2055). Local knowledge can fill the gaps in spatial and historical information (Debolini *et al.,* 2013: 24). Participatory GIS has multiple positive outcomes as it empowers local stakeholders to map their land, while simultaneously contributing to research (Aswani and Lauer, 2006: 66; Debolini *et al.,* 2013: 24). Participatory GIS is a bottom-up approach (Goodchild, 2007: 218).

Participatory GIS or 'crowd-sourcing' allows individuals who are unqualified in GIS and geographic knowledge to map their landscape (Dodge *et al.,* 2011: 370; Fagerholm *et al.,* 2012: 422). The literature supporting this method is increasing due to the success of local stakeholders mapping their environment (Fagerholm *et al.,* 2012: 422). The accuracy of the results may not be of high standards nor acceptable for some researchers (Goodchild, 2007: 211; Dodge *et al.,* 2011: 370) making it necessary for an expert to review the results. The different knowledge levels of individuals' means that some participants are more valuable to the study by providing accurate knowledge while others may not. There can also be a bias towards a certain area or group of people from a community and this must be accounted for by the expert. Individuals voluntarily participate in the study (Dodge *et al.,* 2011: 370). Therefore, this form of mapping is named Volunteered Geographic Information (VGI). This is innovative in the GIS world and even the geography discipline as VGI can become an important tool to better understand the world (Dodge *et al.,* 2011: 371, 377). Base maps can be more revealing when local knowledge is included (Debolini *et al.,* 2013: 24) as stakeholders are able to provide valuable spatial knowledge (Grêt-Regamey *et al.,* 2013: 34). The greater the understanding of the localised area is the more meaningful and informative the knowledge will be, for example a long standing resident will be more helpful than a visitor to an area. Activities in the area can be compared to those in other areas (Dodge *et al.,* 2011: 370). VGI promotes the incorporation of areas previously unnoticed by greater region mapping (Goodchild, 2007: 220; Dodge *et al.,* 2011: 370). There are disadvantages with VGI in that it is a time-consuming process and individuals may need motivation to take part in the study (Dodge *et al.,* 2011: 377). There is also a need to be connected to the Internet in some VGI studies (Goodchild, 2007: 217).

Fagerholm *et al.* (2012) respect the inclusion of local knowledge because maps produced are based on knowledge and not assumptions. The authors demonstrate how spatial research can incorporate local stakeholder knowledge. The involved stakeholders mapped important landscape services. This knowledge can be analysed scientifically and provides needed generalisations in some cases (Fagerholm *et al.*, 2012: 430). There was a correlation between time spent in the area and the number of areas mapped (Fagerholm *et al.,* 2012: 430). Areas mapped frequently showed the importance to stakeholders (Fagerholm *et al.,* 2012: 430). One of the difficulties with participatory GIS is representing the frequency of highlighted features on the map.

Debolini *et al.,* (2013) conducted a participatory GIS study where local community members were asked to map suitable agricultural areas. The map used in the face-to-face interviews needed to be simple so that unskilled locals would understand it (Debolini *et al.*, 2013: 25). The authors believe that this method is integral for informed decision making. Quantitative and qualitative spatial knowledge can be gained through interviews involving maps (Debolini *et al.,* 2013: 31). The mapped area could be compared between interviewees because the interviews were structured (Debolini *et al.,* 2013: 32). To account for the perceived lower accuracy of these participatory maps, physical maps were also created (Debolini *et al.,* 2013: 32).

Knowledge of the ecosystems relationship with the social systems is held by the local stakeholders (Grêt-Regamey *et al.,* 2013: 34) even if they do not understand the relationships. Information about successful and failed past management approaches as well as the ecosystem’s response to these approaches can be provided by local stakeholders (Grêt-Regamey *et al.,* 2013: 34). VGI does not only involve a map-based interview. Local stakeholders can create maps by taking GPS points and can provide graphic spatial data through geotags and georeferencing (Goodchild, 2007: 215, 216). With many mapping agencies unable to sustain continual map updates, there is a possibility the need for VGI will increase (Goodchild, 2007: 217).

3.7.3. Beach Surveys

Informed decision making in the management of coastal resources increases the success of the approaches and policies implemented (O'Regan, 1996: 192). Therefore, reliable and current information on beach dynamics is important. As discussed previously, different coastal processes shape the coastline. Therefore, that repetitive sampling of beach profiles is needed to understand the coastal processes and allow for informed decision-making in management has long been recognised (Morton *et al*., 1993: 702; O'Regan, 1996: 194; Andrade and Ferreira, 2006: 995). Beach surveying provides a one-dimensional view of beach elevation from a permanent reference point (Morton *et al*., 1993: 703). Surveying profiles involve stopping at a sequence of points to take a measurement (Morton *et al*., 1993: 704). Beach monitoring information is no longer limited to the academic world as government agencies and local organisations are interested in beach dynamics for construction, insurance and management purposes (Morton *et al*., 1993: 702). Three common limitations in beach surveys are presented by Morton *et al*. (1993: 703). These limitations include the loss of permanent markers of profiles/cross sections, the time needed to survey beaches and estimating the distance between cross sections. If no reference point is used the 'view' in elevation will not be the same.

"A total station is an electronic tacheometer, which is a geodetic instrument to measure slope distance, and horizontal and vertical angles of a target point" (Feng *et al*., 2001: 134). Differential Global Positioning System has improved accuracy through the use of two GPS receivers where one receiver moves with the user, the rover, to unknown coordinates and the other receiver is un-moving in a known position, the base. The receivers are linked via satellites to determine the corrected coordinates of the rover (El-Rabbany, 2002: 71). Baptista *et al.* (2008) and Morton *et al*. (1993) compared common survey equipment: total stations and DGPS. While total stations have provided the most accurate beach survey results for a number of decades, GPS accuracy is remarkable (Baptista *et al.*, 2008: 1517). Total stations are conventionally used in beach survey studies (Andrade and Ferreira, 2006: 995; Baptista *et al.*, 2008: 1516). Large beaches have often not been measured entirely because conventional surveying techniques were limiting (Morton *et al*., 1993: 702). The area commonly measured in cross sections is from the fore dunes to the low water mark (Baptista *et al.*, 2008: 1517).

Cross sections are measured along the beach with even or uneven intervals (Baptista *et al.,* 2008: 1517, 1521). The advantages of using total stations are the ease of data transfer, high accuracy, simple operation of the equipment, spatial accuracy is maintained when viewed at different scales and inaccessible places can be reached with the rod and prism (Lavine *et al.,* 2003: 88). The beach cross sections measured in total station studies do not provide a representative depiction of beach morphology as interpolation is needed for the areas between cross sections (Baptista *et al.,* 2008:1516). This equipment requires at least two skilled users and it is expensive (Lavine *et al.,* 2003: 88, 89; Andrade and Ferreira, 2006: 995). This surveying method is time-consuming, particularly when the beach length and width is several kilometres (Baptista *et al.,* 2008: 1517) as the total station is heavy and cumbersome (Lavine *et al.,* 2003: 88). Due to this constraint, the number of cross sections measured is low and problems can arise when data for the areas between the cross sections are generalised (Baptista *et al.,* 2008: 1517).

Along with total stations, GPS surveys are common (Baptista *et al.,* 2008: 1516). Since the 1990s, GPS devices have been used in beach surveys (Baptista *et al.,* 2008: 1517). Attaching a GPS to a quad bike and driving along the beach provides continuous measurements of the beach (Baptista *et al.,* 2008: 1516). GPS uses in beach studies include being the surveying method or ground-truthing aerial images (Baptista *et al.,* 2008: 1517-1518). The use of vehicles on South African beaches has been prohibited since December 2001 to ensure the conservation of animal habitats, e.g. the African Black Oystercatcher and the White-fronted Plover (Williams *et al.,* 2004: 79). Therefore, quad bikes were not used in this study. DGPS measurements were done on-foot. GPS can present a broader morphological view by conducting vertical and horizontal cross sections to form a grid which will give more detail for interpolation (Morton *et al*., 1993: 703). GPS devices find the location using satellite positions in that the position of each satellite and the distance between them is known, as well as the distance of the satellites to the GPS device (Baptista *et al.,* 2008: 1517). GPS can be used in all weather conditions and results are continuous (Morton *et al*., 1993: 703).

Differential and absolute are different GPS modes that can be selected (Baptista *et al.,* 2008: 1517). Only one receiver is used when operating in absolute mode, while two receivers are in operation when in differential mode (Higgit and Warburton, 1999: 123; Baptista *et al.,* 2008: 1517). The same satellites are used by both receivers (Morton *et al*., 1993: 704). One of the receivers is placed over a known fixed reference site while the other is used to survey the beach (Morton *et al*., 1993: 704; O'Regan, 1996:195; Higgit and Warburton, 1999: 123;

Baptista *et al.,* 2008: 1517) (Figure 9). Within the differential mode, the receiver can operate in a kinematic or static mode (Baptista *et al.,* 2008: 1517). Differential mode is more accurate than the standard GPS (Morton *et al*., 1993: 704) and total station (Higgit and Warburton, 1999: 123). Centimetre accuracy can be obtained through DGPS in beach surveys (Baptista *et al.,* 2008: 1517, 1521).

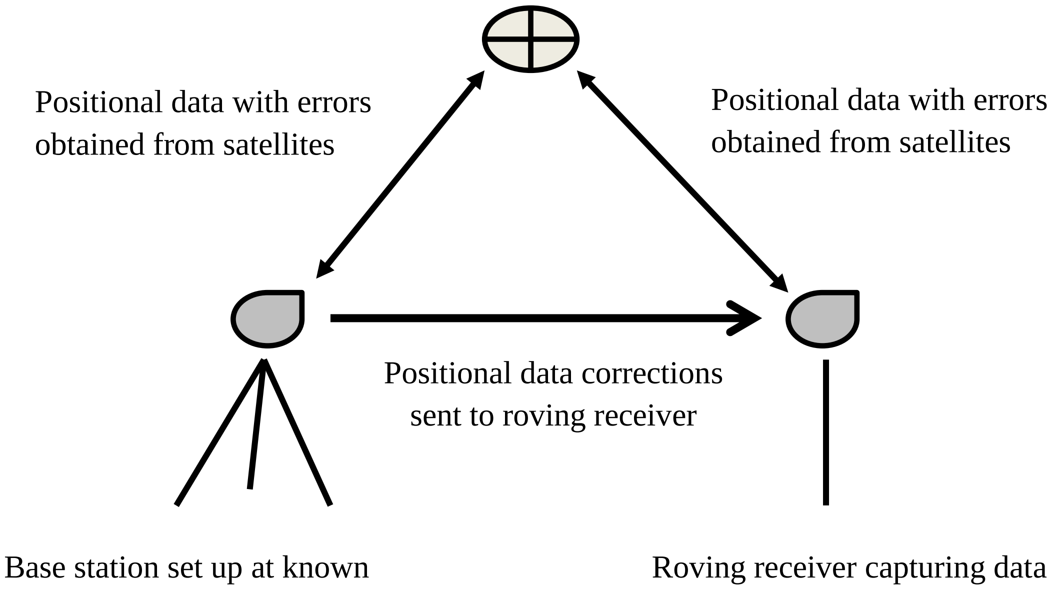


Figure 9: Data transmission of DGPS (adapted from O'Regan, 1996:196)

Beach surveying with a GPS on-foot can also be a time-consuming process, but it is an improvement on the total station (Morton *et al*., 1993: 703; Baptista *et al.,* 2008: 1518). Surveying with DGPS in kinematic mode allows for continuous, rapid and highly accurate results (Morton *et al*., 1993: 704; Higgit and Warburton, 1999: 123). Kinematic mode allows for the receiver to measure while mobile (Morton *et al*., 1993: 704). When using a DGPS on-foot the operator is responsible for keeping the vertical position of the pole (Baptista *et al.,* 2008: 1520). The pole is set a certain height for all measurements (Baptista *et al.,* 2008: 1520). Apart from the high accuracy, advantages of the DGPS include the improved speed of surveys compared to other methods; the ability to survey in rain and wind as well as at night and only one operator is needed to survey (Higgit and Warburton, 1999: 125). In this study the pole was placed on the ground which reduces inaccuracies associated with receivers carried on the operator's person. Digital elevation models (DEMs) can be used to find the slope of the beach (Baptista *et al.,* 2008: 1516).

Baptista *et al.* (2008) further compared total station results with DGPS results. The same profiles were used for both pieces of equipment. The DGPS was in a kinematic mode. The total station was used to measure beach profiles/cross sections first. DGPS points were taken at the markers used to mark beach profiles/cross sections. The DGPS was held in position for a long observation period which provided measurements with 2 mm accuracy. The results of the study showed that there were centimetre differences in the accuracy of the measurements, typically no more than a 3 cm difference. When mapping with a DGPS, the main error to be noted is the shoreline determination by the surveyor (Boak and Turner, 2005: 699). In a study conducted by Morton *et al*. (1993: 704) and O'Regan, (1996: 195) the results showed 0.5 cm error between the two methods (Morton *et al*., 1993: 711).

Benedet *et al.* (2004) surveyed beaches in Florida, USA. Beach surveys measured the beach elevation and started at the vegetation and moved seaward (Benedet *et al.,* 2004: 850). The interval of measurement was dependent on the beach width, with five meters being the maximum interval (Benedet *et al.*, 2004: 850). If there was a change in grade (e.g. dune crests and scarps) measurements were taken within the original set interval of measurement (Benedet *et al.,* 2004: 850).

This study followed the surveying method of Benedet *et al.* (2004: 850) where the interval of measurement changed with the width of the beach and additionally measurements were taken when there was a change in grade.

CHAPTER 4: Methodology

The coastal development on the Cape St Francis/St Francis Bay peninsula over a 50-year period saw many human-induced landscape changes which led to environmental problems in the area that threaten the well-being of the community. Qualitative and quantitative methods were used to investigate the nature and extent of landscape changes to gain a more holistic understanding of the whole system, and the results could potentially aid future management of the area. Each objective had an associated method to achieve it (Table 2).

Table 2: Summary of methods used and their relevance to this research

Method	Location	Objective	Purpose	Scale
Desktop Analysis				
Aerial Images from 1961 to 2011	The Peninsula	1,2 and 4	Delineate landscape features and create a time series map	Large: 1:10 000 to 1: 160 000
Crowdsourcing/ Participatory Approach				
Questionnaires and Personal Interviews	The Peninsula	1, 2 and 4	Determine perception of residents on landscape changes and associated natural events	Local
Media Review				
Newspaper clipping	The Peninsula	2 and 4	Providing context to changes from time series map and substantiate residents perception	Local
Beach/Dune Survey				
Total Station and Differential GPS	The spit, SFB, CSF and SP Dunefield	3 and 4	Determine current (seasonal) changes (erosion or deposition)	Local
Repeating 2007 Survey	The spit and SFB	3 and 4	Determine success of hard and soft defence methods (beach recovery/resilience)	Local

4.1. Mapping landscape features

In order to identify and map landscape features that have changed over the 50-year period, existing GIS data had to be assembled and stored in a geodatabase. Current orthorectified aerial photographs and older, un-georeferenced historic aerial images of the coastal area were collated. These images were obtained from the Chief Directorate National Geo-spatial Information (NGI) who provided updated maps and images of South Africa. Aerial images of the following years were obtained for this study: 1961, 1971, 1978, 1985, 1999, 2009 and 2011. All aerial images prior to 2009 had to be geospatially referenced to allow comparable delineation of landscape features for the respective years. All data was projected to the Transverse Mercator projection with the central meridian of the 25° East, referenced to the World Geodetic System 1984 datum, which was suitable for working at a local area (large scale). Scale varied between 1: 10 000 to 1: 160 000. The ESRI GIS (ArcGIS 10.2) software package was used to perform the delineation process where landscape features were identified and mapped at a scale at or below 1: 3000 to provide an initial representation of how the landscape had changed over the period of development. The 1961 images were used to represent how the area looked in its most natural state while the 2011 images represented the present state of the area, with maximum human-induced change. An initial field survey was done, in order to ground-truth the identified and mapped landscape features from the desktop study. The drainage ditches were one of the features that had to be mapped after the ground-truthing had been completed because identification of these features from aerial-orthophotographs proved difficult. Once all coastal landscape features had been identified and mapped for all the respective years, a time series was created to visually present how the landscape had changed from 1961 to 2011. The aerial images could only provide a brief ‘snapshot’ capturing a particular moment in time and thus another approach had to be utilised to bridge the knowledge gap between the respective years.

The beach width of St Francis Bay and Cape St Francis in 1961 and 2011 was measured and compared. Features identifiable in both years were used to measure beach width from land to shoreline. These years were chosen because of the quality of the aerial photographs.

4.2. Investigating geographical coastal landscape change

Goodchild’s (2007) method was adapted whereby spatial data was collated through the process of crowdsourcing and volunteered geographic information (VGI). This was done through the use of questionnaire surveys and personal interviews; hence employing a more qualitative approach for gathering anecdotal evidence on coastal landscape change over the period of development for the Cape St Francis/St Francis Bay peninsula. The main objective of the interviews was to provide participants with an opportunity to map their own land by depicting ‘areas of interest’ and placing them on a basemap with a temporal scale attached to a particular event (for example the Sand River bridge collapsed in 2007) (Appendix 1). Permanent residents and regular visitors to the area were seen as the primary focus group, particularly permanent residents who had lived in the area for decades and were regarded as the most suitable interviewees for the study. A sampling size of n = 100 was regarded as suitable to provide a good representation and insight into the coastal landscape changes of the peninsula.

4.2.1. Pilot study questionnaires

A pilot study of n = 25 questionnaires were distributed at ‘The Village Square’ in St Francis Bay, which consists of upmarket tenants and merchandisers. The focus group of the pilot study included all the shop owners, as well as shoppers with particular attention placed on estate agents to draw a clear relationship between development and coastal landscape change.

Through the pilot study it became evident that the length of time associated by participant with the peninsula became one of the most important criterias. Although all participants that were willing to take part in the study were included in the questionnaire process. However, participants who lived or had an association with the Cape St Francis/St Francis Bay peninsula for a long period of time (more than 10 years) were asked to take part in a face-to-face interview.

The purposive ‘Snowball’ and ‘Chain’ sampling method was therefore adapted from then onwards, whereby participants were asked for additional participants who had lived in the area for a long time and/or should be included in this study (Teddlie and Tashakkori, 2009: 175). Many interviewees referred to other knowledgeable individuals and thus the method was deemed extremely useful in bridging the above-mentioned knowledge gap.

4.2.2. Face-to-face interviews

Contact details of potential participants were gathered through the ‘Snowball’ sampling method and consequently face-to-face (personal) interviews were arranged. The interviews followed the same structured questionnaire format, but essentially a more semi-structured interviewing format was used to allow room for probing questions to responses (Morse and Niehaus, 2009: 129, 130).

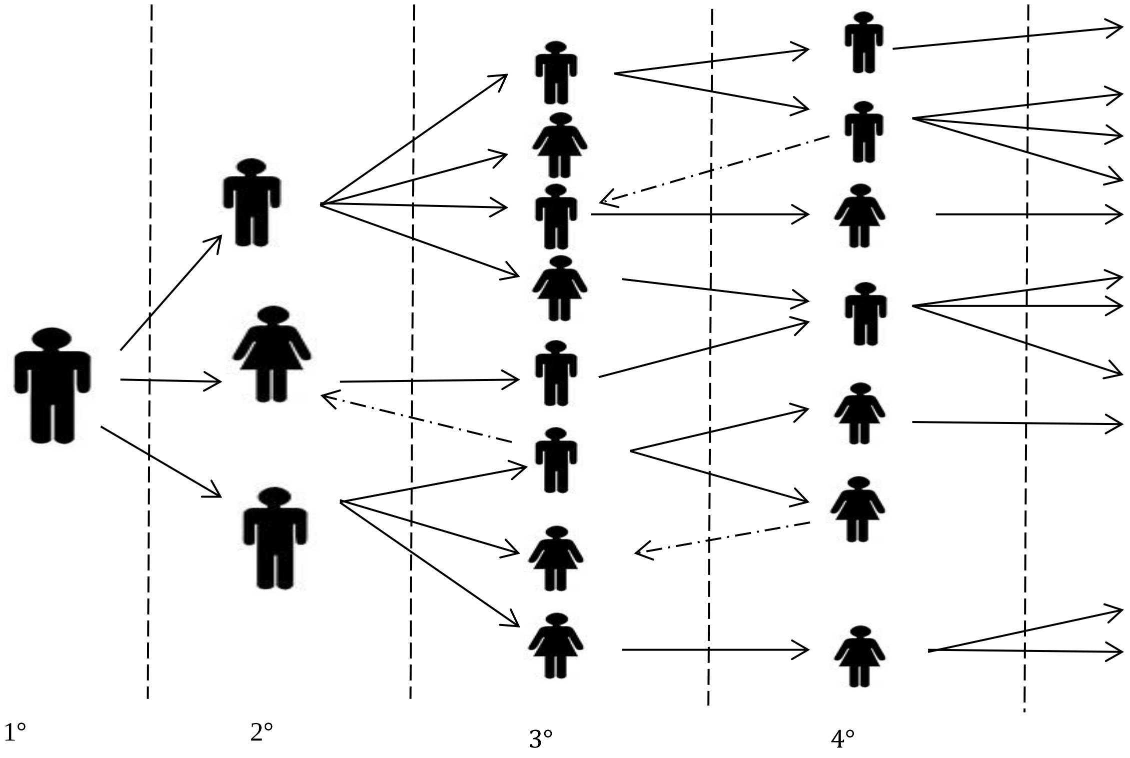


Figure 10: Illustration of the ‘snowball effect’

4.2.3. Telephonic and email interviews, and ethical considerations

Telephonic interviews and questionnaires sent out via email were also conducted, with positive responses. At this point it is important to note that all ethical considerations were taken into account and that participants were informed of the purpose of the study; participants had the right to stop the interviews at any moment in time; and all participants also had the same right regarding anonymity and confidentiality.

4.2.4. Positive outcomes of the questionnaire surveys

Through the personal interviews a form of archival data collection occurred, whereby interviewees shared their private photographs of the Cape St Francis/St Francis Bay peninsula as well as several reports, books and booklets, old newspaper article clippings and physical surveying data (DGPS points) of the spit and St Francis Bay beach from 2007. A total of n = 78 participants were interviewed and/or responded. All socioeconomic groups were taken into account as questionnaires were also distributed in the Sea Vista Township, allowing as many potential interviewees as possible to participate in the study.

4.2.5. Randomisation of respondents

Randomisation of the questionnaire and interview respondents was assured through the ‘Snowball’ sampling method and the inclusion of different socioeconomic groups. Questionnaires were undertaken at ‘The Village Square’, the beaches and outside a grocery store in the Sea Vista Township.

4.2.6. Creation of an expert map and a media-reviewed timeline

Questionnaire and interview responses were transformed into an expert map in order to investigate whether the residents and frequent visitor’s knowledge of the peninsula coincided with changes seen in the time series maps. Changes documented on the peninsula by local stakeholders and newspapers were amalgamated into a timeline which formed the media review part of this study. The newspaper clippings provided by a permanent resident proved to be advantageous as there was no online database available.

Information gathered from respondents showed a significant concern for beach erosion (particularly that of St Francis Bay and the spit). Tourists are attracted to clean, long and wide sandy beaches due to their aesthetically appealing look (Turnstall and Penning-Rowsell, 1998: 322) and so field surveys were implemented to assess seasonal beach changes.

4.3. Field surveys of measurable selected features

As discussed in the literature review, coastal zones belong to one of the most dynamic and changing environments on Earth (Woodroffe *et al.*, 2011: 412), particularly sandy beach morphology. Continual changes of these beaches are influenced by wind, wave and tidal processes (Andrade and Ferreira, 2006: 995) which may occur quickly or slowly over a temporal scale (Bird, 2000: 95). Tinley (1985: 10) stated that the dunes of the peninsula nourished the beaches, while sand of the beaches also nourished the dunes and thus a co-relationship was formed. For the purpose of this study the St Francis Bay and spit beaches represented the impacted areas; whereas the Cape St Francis beach was considered the less impacted, ‘more natural’ beach. The Shark Point Dunefield was also investigated as it was considered one of the only functioning dunefields.

Along with the researcher’s own beach surveys, surveys taken in 2007 of the St Francis Bay and spit beaches by Maarschalk and Partners Incorporation were repeated. Permission was granted by a prominent member of *The Beach Trust* (which no longer operates) to repeat these surveys. Cross sections corresponded with the researchers own surveys. The data from 2007 and 2014 was then compared to assess whether erosion or deposition had taken place.

4.3.1. Pre-fieldwork planning

Instrument use training was undertaken prior to data collection. Pre-fieldwork planning involved the division of beaches into approximately equally spaced transects (cross-sections) covering the entire beach and dune area. This was done at St Francis Bay, the spit and Cape St Francis beaches, as well as the Shark Point Dunefield connected to the Cape St Francis beach. It was essential to have a cross section located close to either end of each beach. The number of cross sections of each area determined by the length and the intervals of measurements was determined according to the width. Wind resistant markers of one and a half to two meters long poles were placed at the top of each transect for quick identification when repeating surveys. As in the case of St Francis Bay, revetment rocks directly below the poles were also marked with a red cross in case markers were lost. GPS locations were recorded should the poles disappear. At each pole transect pictures were taken with North, East, South and West bearing for locality and recording change. Cross sections and a long profile were measured at low tide for maximum beach width. It was of utmost importance that the surveying window during low tide be identified, as St Francis Bay and the spit beaches are significantly narrower during high tide; to the extent that some beach areas (littoral zones) disappear completely.

4.3.2. Surveying period

Surveys were conducted at full moon every three months from October 2013 to October 2014 to show seasonal changes of the selected surveyed features. Beach surveys followed the same data collection sequence (the artificial spit, St Francis Bay and then Cape St Francis) to ensure that the beaches would be affected by the same low tide variables.

4.3.3. Equipment

The equipment used for the study consisted of:

- A total station (Trimble) and tripod
- A differential GPS (Geomax Zenith 10/20) and tripod
- 50 meter measuring tape
- Sieve shaker and sieve sets things
- Barington MS2 susceptibility meter

4.3.4. Data collection

4.3.4.1. Total Station

In October 2013 surveys were measured with the total station and tripod. Standard surveying techniques were used as discussed in the literature review by Morton *et al.* (1993), Benedet *et al.* (2004), Andrade and Ferreira (2006) and Baptista *et al.* (2008). Due to varying beach widths, measurements were taken at one meter intervals at the spit, two meter intervals in St Francis Bay and five meter intervals in Cape St Francis, initially using a measuring tape. Points were taken between specified intervals if there was a morphological change. Cross sections always started at the furthest point from the shoreline (either on or before the vegetated spit, revetments or vegetated stabilised dune) to the shoreline where the sand was saturated. This ensured the inclusion of the complete littoral zone, where the most change occurred. A longitudinal profile of the shoreline was also measured in order to see what changes occurred there. The Shark Point Dunefield consisted of cross sections and longitudinal profiles. Points were only surveyed when morphological changes occurred or where bedrock and rocks were visible.

4.3.4.2. Differential GPS

From January to October 2014 a differential GPS with Rover instrument were used to survey the cross sections and long profiles. Control points for the base station were found and setup in stable locations; for example, a car park was used in St Francis Bay. The reason for the equipment change during the study was due to the non-functioning total station. Intervals between points taken were adjusted slightly during each data collection period as the beaches continually extended in St Francis By and the spit and as a result of the small surveying window of the beaches during low tide. The interval change also exceeded the suggested maximum five meter intervals (Benedet *et al.*, 2004: 850) due to the extensive width of the Cape St Francis beach.

4.3.4.3. Sand samples

Sand samples were collected at the top, middle and bottom of three cross sections from St Francis Bay and Cape St Francis, while only one from the spit and the Shark Point dunes for an indication of particle size and magnetic susceptibility changes. The sizes of the sand sample were approximately three handfuls. Sand samples were also collected from potential sand source sites (for example Oyster Bay) to compare the magnetic susceptibility readings.

4.3.5. Processing

DGPS points both of impacted and less impacted sites were then digitised in Microsoft Excel to create line graphs of each cross section and longitudinal profile to determine what changes occurred over the surveying period. This allowed for morphological changes to be observed and the beach extent per cross section to be determined so as to indicate whether erosion or deposition happened.

DGPS points were also added into ArcGIS 10.2 to provide a visual representation of the cross sections and the longitudinal profiles. This was not only done to investigate shoreline changes but primarily to determine an approximated net volume per surveying month from January to October 2014. Considering that the total station data (October 2013) could not be added or transcribed into ArcGIS, the volumetric readings were not calculated for that month. Net volumetric readings were calculated using standard processing tools in ArcGIS, namely: inverse distance weighting (IDW) and surface volume (3D Analyst).

4.3.6. Laboratory analysis

Sand samples were analysed from beach and dune cross sections, as well as potential source samples that were taken from the Oyster Bay beach, the Oyster Bay Headland Bypass Dunefield and the Sand River. Sand samples were dried at 40° C to ensure the magnetic properties were not changed, then sieved and weighed to determine particle size distribution. The Barington MS2 Susceptibility Meter was used to measure the low frequency parameters.

4.4. Conceptual model

The inclusion of all three methodological approaches aimed to develop an improved understanding of the landscape highlighting past and present changes as a direct result of human settlement and their socioeconomic development, which may inform future planning and management of the peninsula.

CHAPTER 5: Results

The results yielded from the qualitative and quantitative methods are presented in this section in the form of maps, tables, figures and photographs to highlight the historic and seasonal changes the peninsula had to face over the period of development. Landscape features presently found on the peninsula are presented in this section along with a time series map, an expert participatory map, a media-reviewed timeline and the results yielded from the beach and dune surveys. A conceptual model was created to illustrate the sediment movement over the Cape St Francis/St Francis Bay peninsula.

5.1. Feature and time series mapping showing historic change

The human-made and natural landscape features situated on the Cape St Francis/St Francis Bay peninsula are illustrated in Figure 11. Human-made coastal landscape features that were identified on the peninsula were: the urban settlements (Oyster Bay (A1), St Francis Bay (A2), Cape St Francis (A3), The Marina Canals (A4), Santareme (A5) and the Sea Vista Township (A6)); infrastructural development ((Port St Francis (B1) and the industrial sector (B2)); the Golfing Estates (St Francis Bay Community Golf Course (C1) and the St Francis Links (C2)); the artificial spit (D); the drainage ditches (E1-E3); and the proposed Thyspunt nuclear power plant (F). Alien vegetated stabilised land was not included in the coastal landscape features map. The natural landscape features on the landscape include: sandy (G1-G5) and rocky (G6-G9) shores; active (H1 and H3) and slightly impacted (H2) dunefields; the Kromme River (I1) and its Estuary (I2); the ephemeral Sand River that drains the dunefield (above the R330 Sand River bridge (J1) and below the bridge towards the Kromme River Estuary (J2); water bodies that included dams (K1), wetlands (K2), dune pans in the dunefields (K3) and natural damming behind Santareme known as the Thatchfarm (K4), the Sea Vista aquifer (K5); and the nature reserves (L).

The most significant change that was observed on the Cape St Francis/St Francis Bay peninsula consisted of development growth versus dune loss over the period of development presented in Figure 11. There was small urban development seen on the peninsula in 1961 with the Oyster Bay development, Seal Point Lighthouse, the Hulett’s homestead and a small fishing village (which consisted of eight rondavels) being present whilst dunes covered most of the peninsula with the eastern end of the Oyster Bay Headland Bypass Dunefield extending to the St Francis Bay beach.

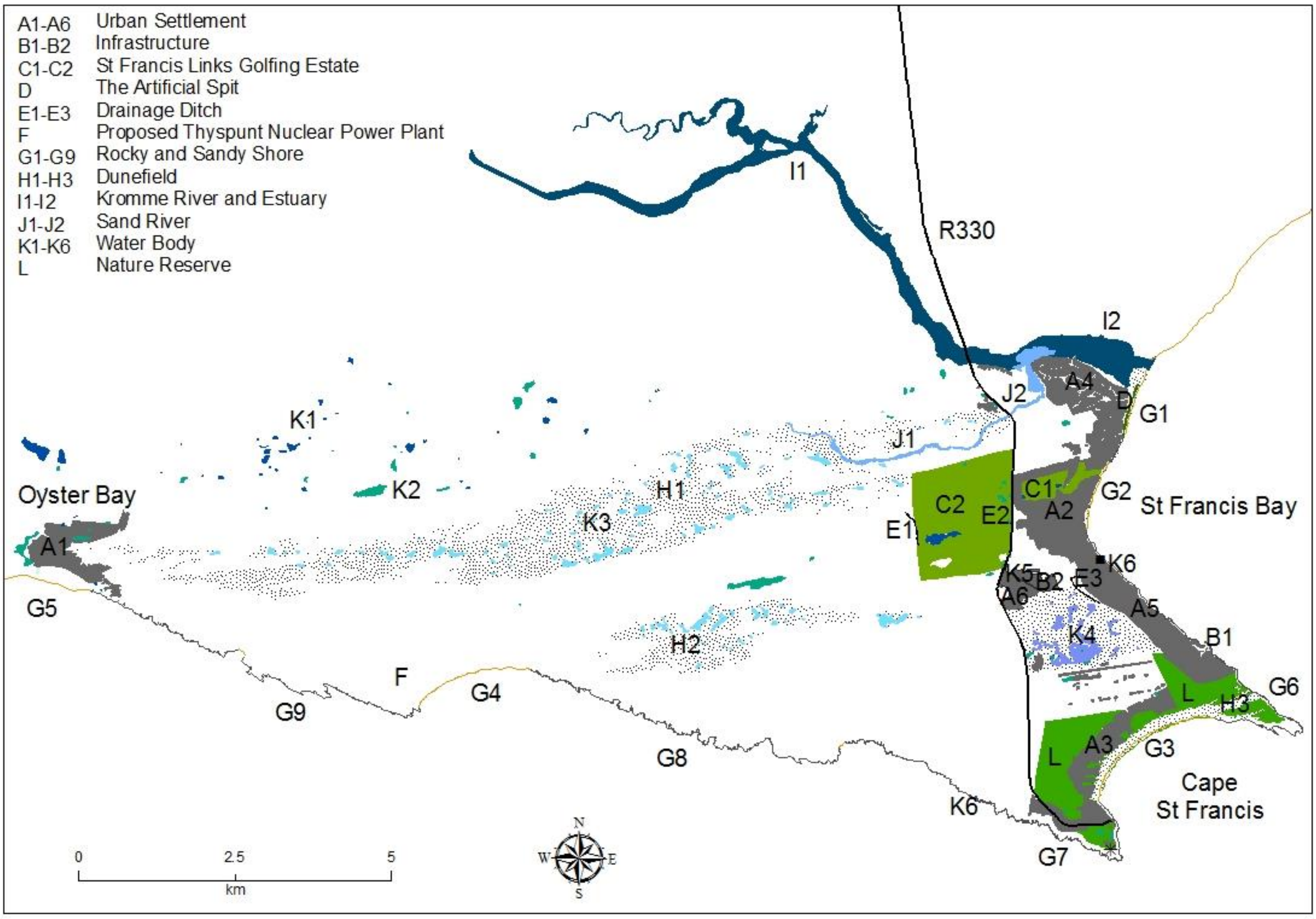


Figure 11: Human-made (A-G) and natural (H-O) landscape features of the Cape St Francis/St Francis Bay peninsula

Thus 1961 represented the most natural state of the peninsula for the purpose of this study. Over the following 10 year period development on the peninsula increased, which was seen at Oyster Bay, St Francis Bay, Cape St Francis and the first Canal was dredged (Figure 12). During this development phase dune loss was observed, particularly those situated close to Oyster Bay, Thyspunt, and the newly developed St Francis Bay fishing town and where the R330 road crossed the dunefields. From 1971 to 1978, urban development growth was experienced in St Francis Bay and Cape St Francis as well as the development of the first golf course in the coastal area close to the R330 road known as the St Francis Bay Community Golf Course. Dune loss was primarily evident in Santareme; however dunes further diminished close to the R330 road. By 1978 the Kromme River Bridge was constructed and the R330 route changed. Over the next seven years (1978 to 1985) development continued in this coastal area whereby the urban expansion was seen in Oyster Bay, St Francis Bay, the Canals, Cape St Francis and the newly developed Santareme situated on the right hand side of Bruces Beauties. Consequently, a decrease in dunes covering the coastal area was particularly seen in the Santareme Dunefield, as well as the Oyster Bay Headland Bypass Dunefield, which no longer extends to the St Francis Bay beach, but stretches over the R330 road. By 1999 Santareme and the old golf course were fully developed and there was a continual expansion of all towns. At this point Port St Francis and the airstrip were present on the peninsula. As a result of the development, dunes have decreased. The little dunes between Oyster Bay and Thyspunt have disappeared completely, very little of the eastern toe of the Oyster Bay Headland Bypass Dunefield remains, the Santareme Dunefield disappeared completely and a decrease was also visible in the Thysbaai Dunefield. Over the next 10 years the Cape St Francis/St Francis Bay peninsula had reached its maximum development state (classified as its most ‘stabilised phase’) where the construction of the St Francis Links Golfing Estate occurred. An expansion of all towns took place, but a predominant change was presented at Oyster Bay and the Canals. At this point the Thatchfarm was also developed behind Santareme. Over the 10 year period, dune loss continued whereby the Oyster Bay Headland Bypass Dunefield had reduced in width and the eastern end no longer extended beyond the R330 road. A reduced Thysbaai Dunefield was seen on the peninsula at this point. Though no development growth can be established from the time series map from 2009 to 2011, a decrease in the Oyster Bay Headland Bypass Dunefield and Thysbaai Dunefield was evident. However, the little Shark Point Dunefield stretching across one of the heads of the headland remained active throughout the period of development and had experienced little change through the anthropogenic impacts.

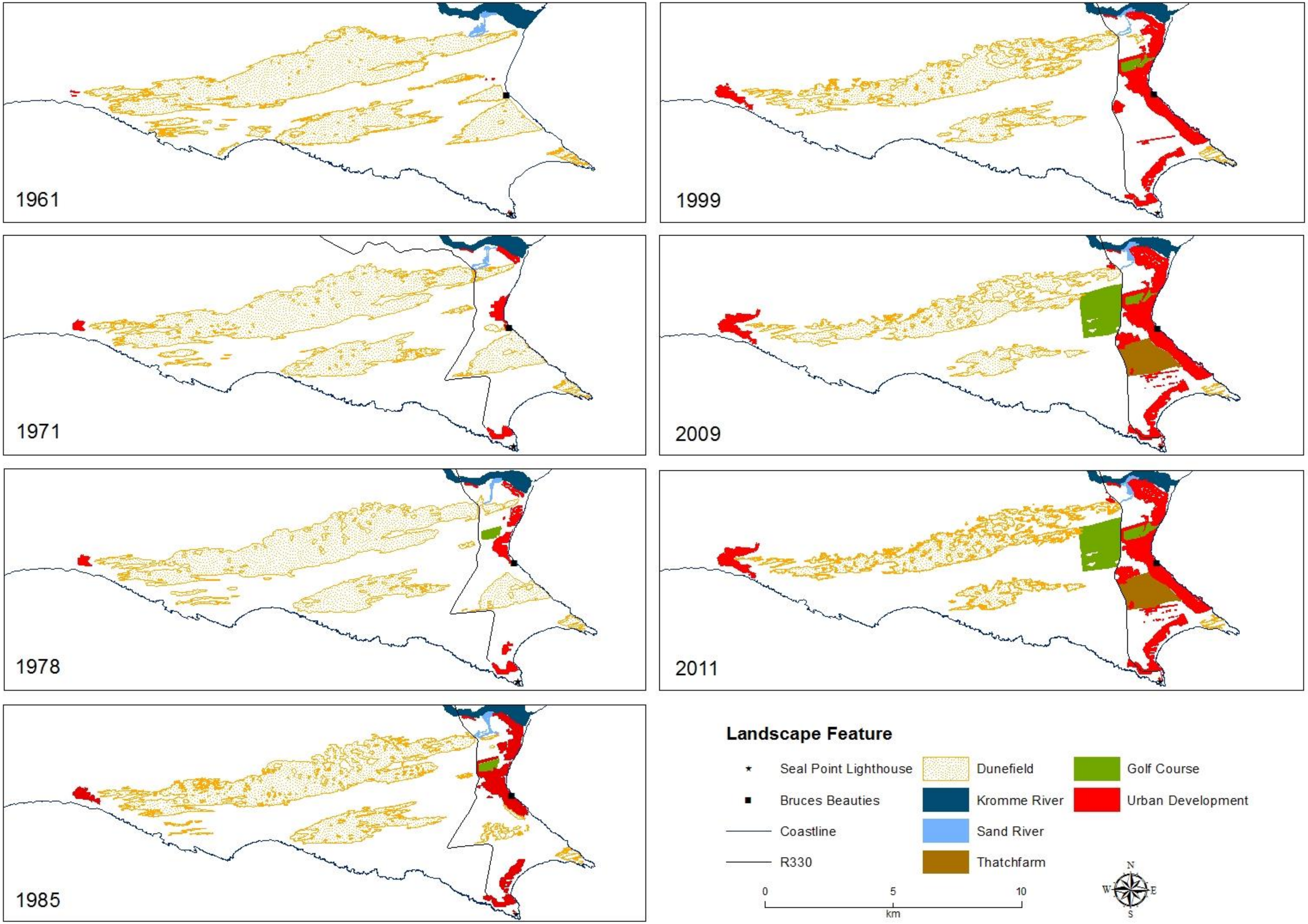


Figure 12: Time series mapping of changes to the peninsula from 1961 - 2011

Table 3 was generated from the time series map data to highlight the development and dune presence trends of the peninsula. A second trend assessment was the dune loss to vegetation which compared to dune loss and to development. Although continual development growth had taken place on the peninsula, the most drastic development growth was seen between 1999 and 2009, whereby the peninsula development had increased by a staggering 53 % (Table 3) which was more than double that of 1999. This was, therefore, regarded as the most significant development 'boom phase'. The other two prominent development 'boom phases' occurred between 1971 and 1978 (17 %) and 1985 and 1999 (16 %) respectively. It is also important to note that over the seven year period (1978-1985) only five percent of development growth had taken place whereas from 2009 to 2011 there was no urban development seen from the aerial images. This could be because free building plots were included into the urban development layer. Although dune loss occurred throughout the development phase, the most significant loss occurred between 1978 and 1985 with 17 %, followed by 13 % (1999 to 2009) and 12 % (1985 to 1999). The least dune loss occurred from 2009 to 2011 where only four percent was lost, as was expected from the short time increment. In total a staggering 66 % of mobile sand dunes were lost of which 58 % was lost to vegetation and only eight percent was directly lost to urban development.

Table 3: Dune area and development change over the 50-year period

Year	Area of Present Development (ha)	Total Dune Area (ha)	Dune Present (ha)	Dune Loss (ha)	Change	
					Loss to Vegetation (ha)	Loss to Development (ha)
1961	2.6 (0.2%)	3023.8 (100%)	2944.9 (97.4%)	78.9 (2.6%)	78.8 (2.6%)	0
1971	97.2 (8.8%)	3023.8 (100%)	2608.8 (86.3%)	415.0 (13.7%)	415.0 (13.7)	0
1978	286.0 (25.9)	3023.8 (100%)	2413.5 (79.8 %)	610.3 (20.2%)	561.1 (18.6%)	49.1 (1.6%)
1985	345.9 (31.3%)	3023.8 (100%)	1897.0 (62.7%)	1126.8 (37.3%)	938.5 (31.1%)	188.2 (6.2%)
1999	518.7 (46.9%)	3023.8 (100%)	1547.2 (51.2)	1476.6 (48.8%)	1231.2 (40.7%)	245.3 (8.1%)
2009	1105.5 (100%)	3023.8 (100%)	1153.9 (38.2)	1869.9 (61.8%)	1615.6 (53.4%)	254.3 (8.4%)
2011	1105.5 (100%)	3023.8 (100%)	1030.7 (34.1)	1993.1 (65.9%)	1738.8 (57.5%)	254.3 (8.4%)

5.2. Expert mapping and media-reviewed timeline

Figure 13 shows a basemap of the peninsula with the crowdscourcing data overlaid on it. It is rated according to the number of respondents who identified relative areas impacted by natural events as a result of human-induced changes. Greener features show impacted areas that only a few respondents identified while more red areas symbolize severely impacted areas that most respondents acknowledged. For example, the Sand River was classified as a severely impacted area because the R330 Sand River Bridge had collapsed several times in the past during flooding, damaging the only entrance to and exit out of the Cape St Francis/St Francis Bay peninsula, while The Canals were perceived to be a less impacted area. Figure 134 to Figure 24 are a collection of photographs which support the mapped features presented in Figure 13.

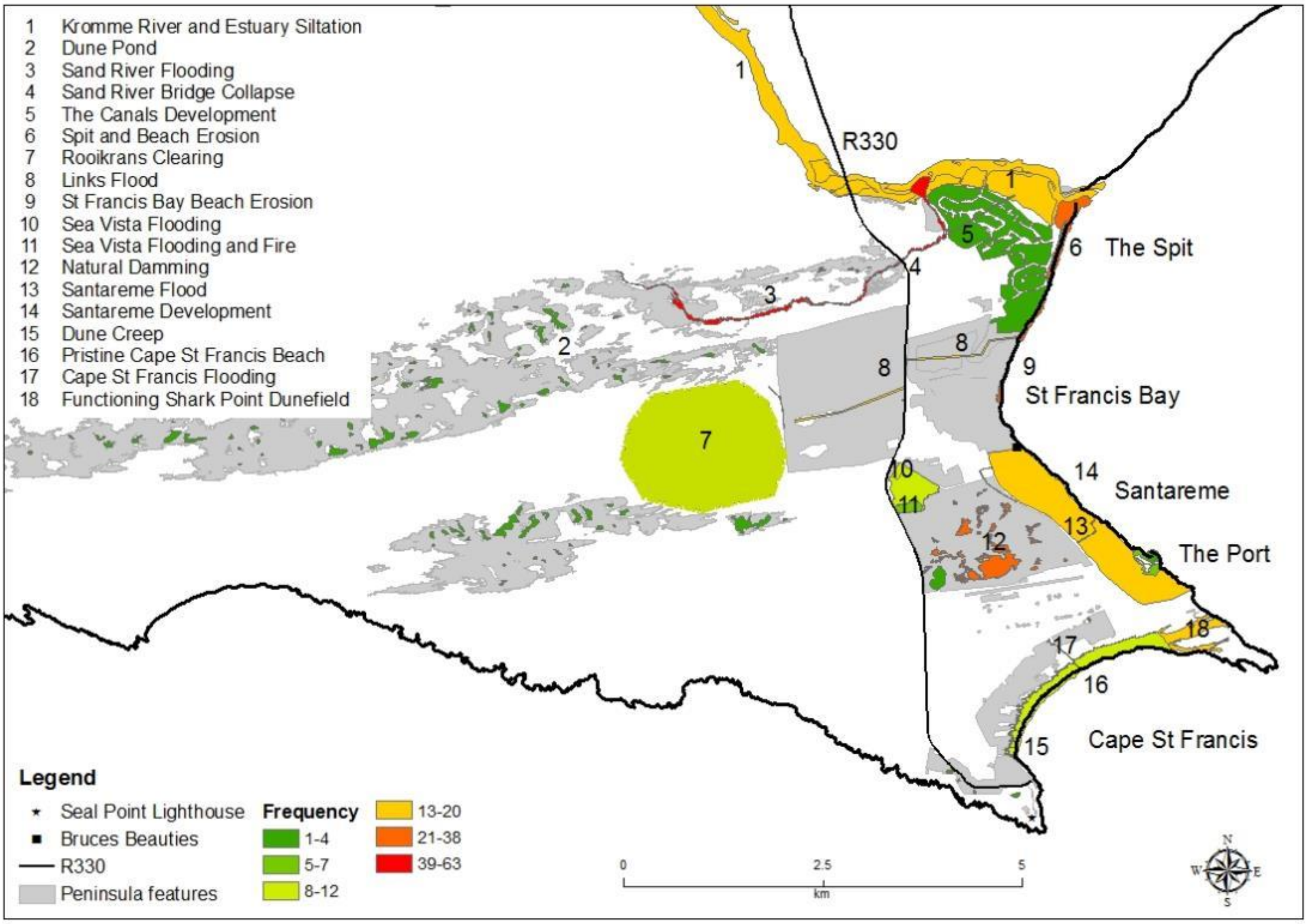


Figure 13: Crowdsourcing map of the ‘problem’ features and events highlighted by participants

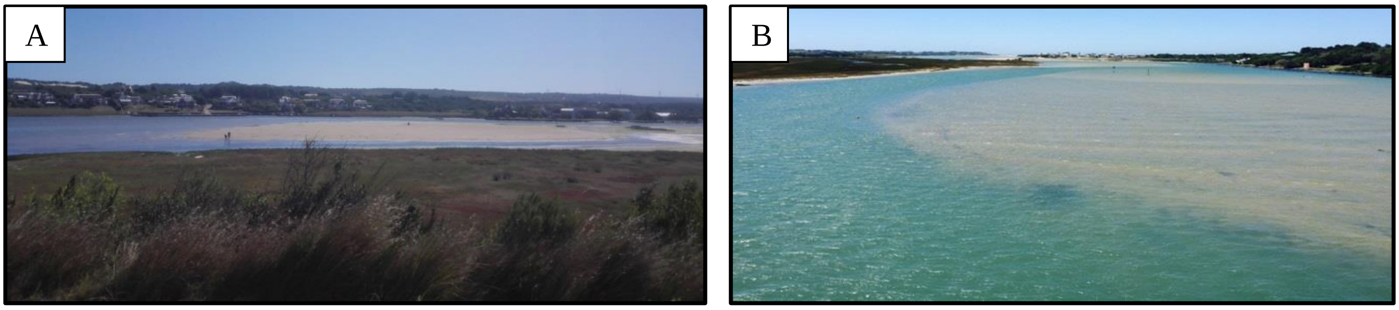


Figure 14: Growing Sand Bank in the Kromme River [A] and estuary [B] (Photo: Miller, 2014 [A]; Schroeder, 2014 [B]) (1 in Figure 13)

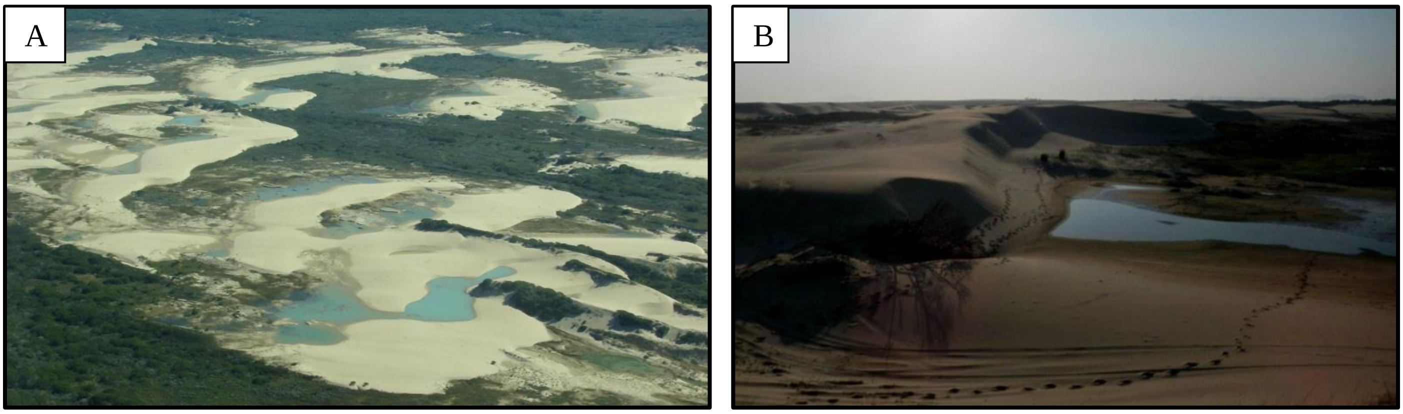


Figure 15: Dune ponds in the Oyster Bay Headland Bypass Dunefield (Photo: Cowling, 2007 [A]; Miller, 2013 [B]) (2 in Figure 13)

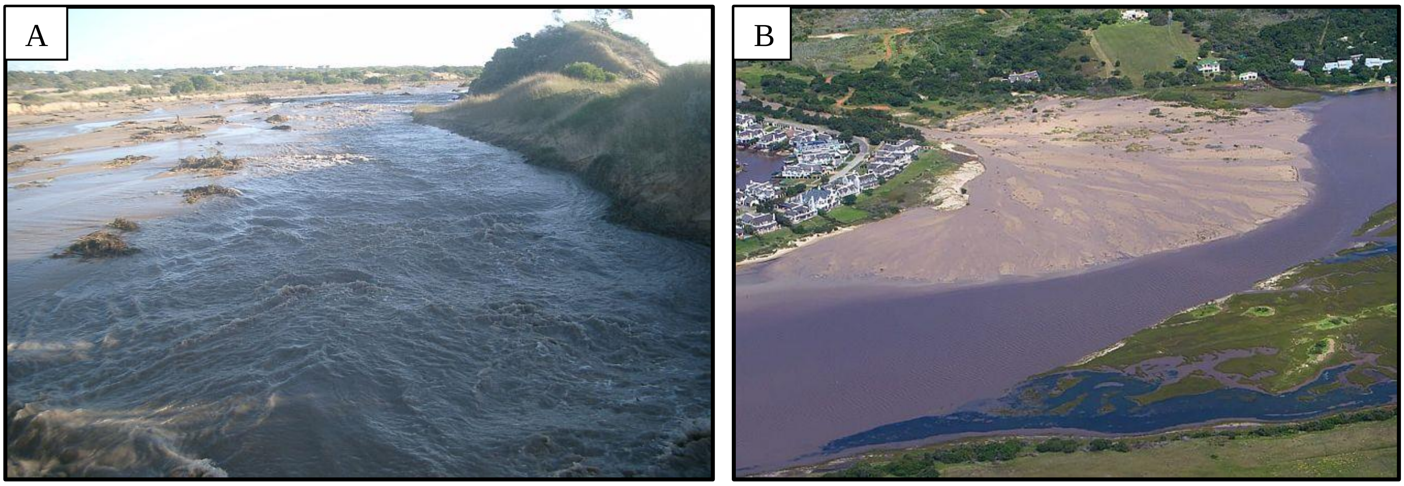


Figure 16: Sand River floods of 2011 [A] and 2012 [B] (Photo: Cowling, 2011 [A] and 2012 [B]) (3 in Figure 13)

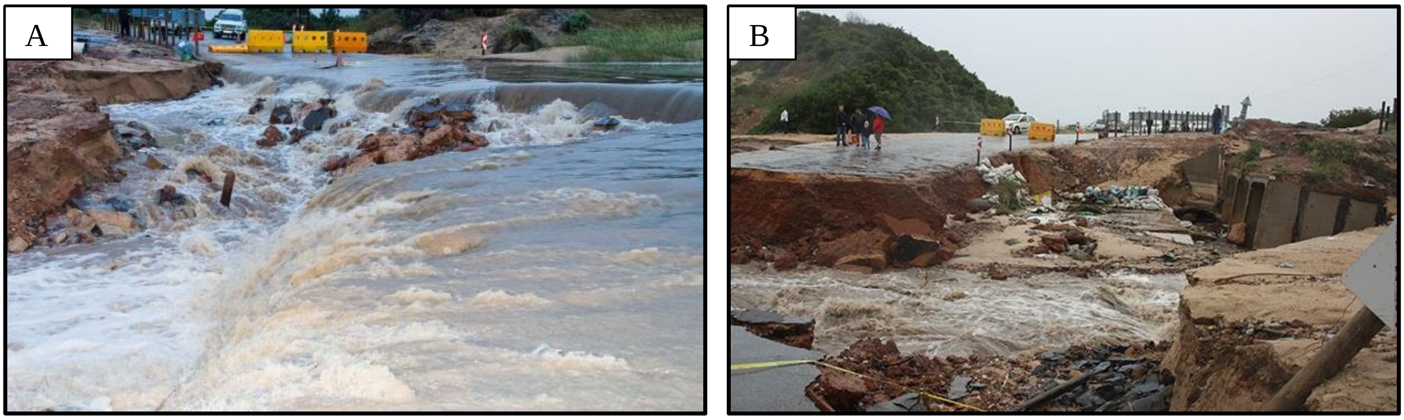


Figure 17: Sand River Bridge 2012 flood and bridge collapse (Photo Wright, 2012) (4 in Figure 13)

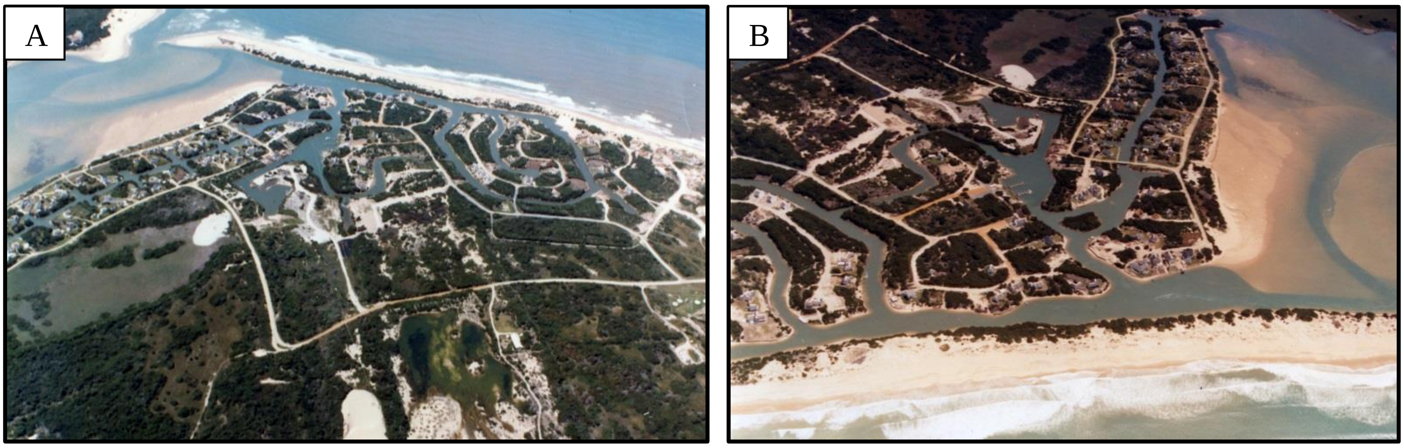


Figure 18: Early canal system development (Photo: Hulett, n.d.) (5 in Figure 13)

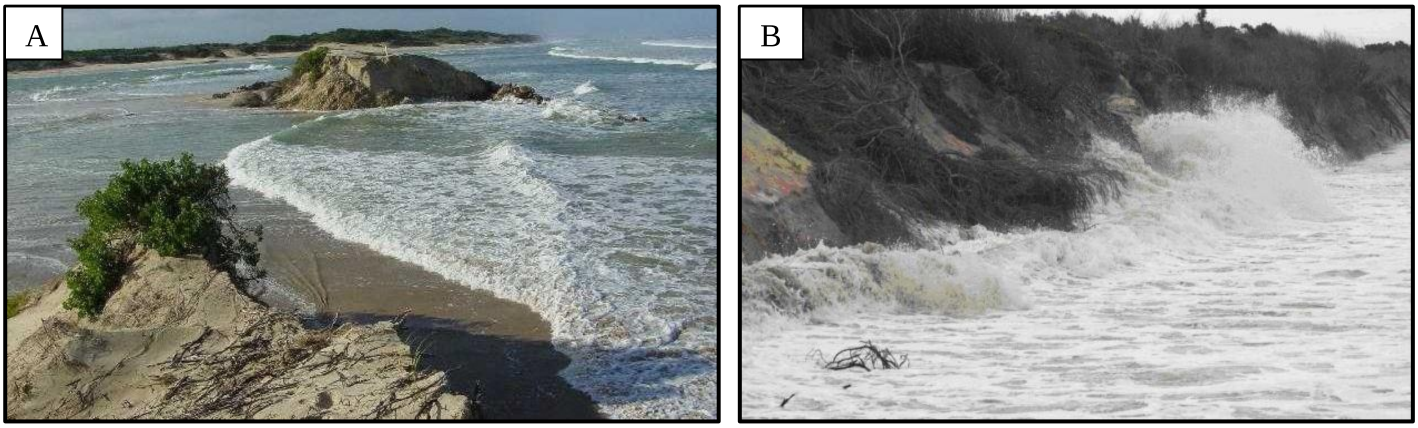


Figure 19: Spit breach in 2003 [A] and waves reaching up whole beach [B] (Photo: Bosman, 2003 [A]; St Francis Chronicle, 2011 [B]) (6 in Figure 13)

Figure 20: St Francis Links flood in 2007 [A] and 2011 [B] (Photo: Bosman, 2007 [A]; Mortimer, 2012 [B]) (8 in Figure 13)

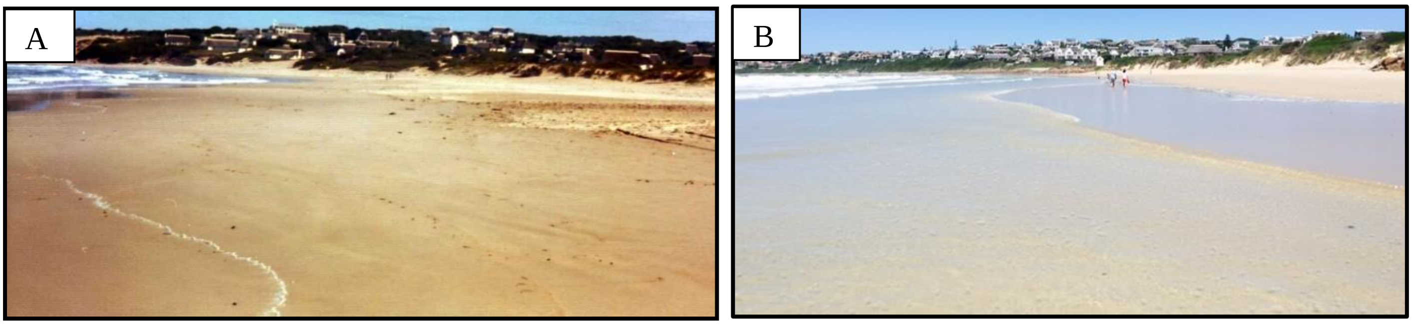


Figure 21: St Francis Bay beach in the 1980s [A] and in 2014 [B] (Photo: Taylor, n.d. [A]; Schroeder, 2014 [B]) (9 in Figure 13)

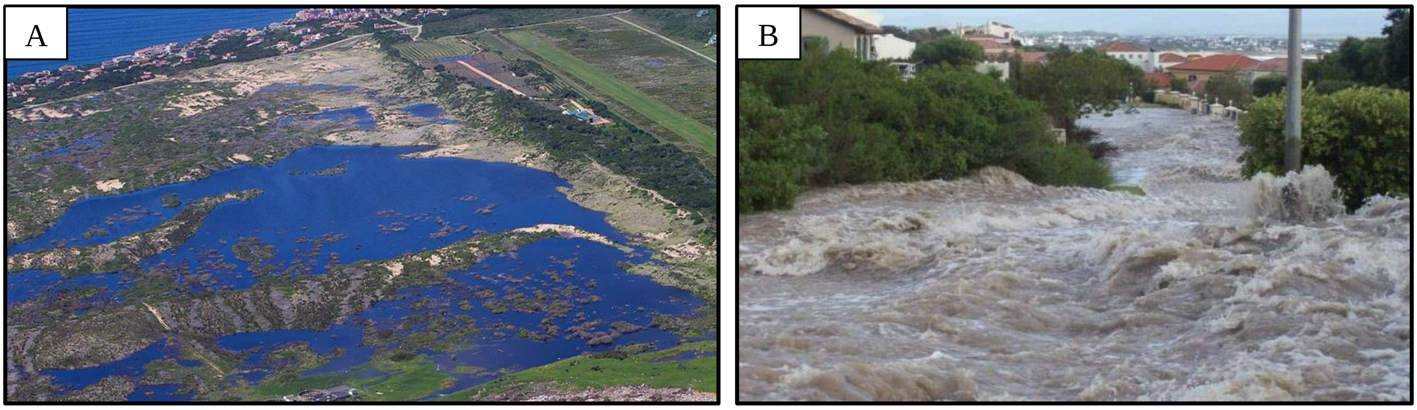


Figure 22: Dune ponds in Thatchfarm behind Santareme development [A] and Santareme flood in Tom Brown Boulevard [B] (Photo: Cowling, 2012 [A]; Macleod, 2012 [B]) (12 and 13 in Figure 13)

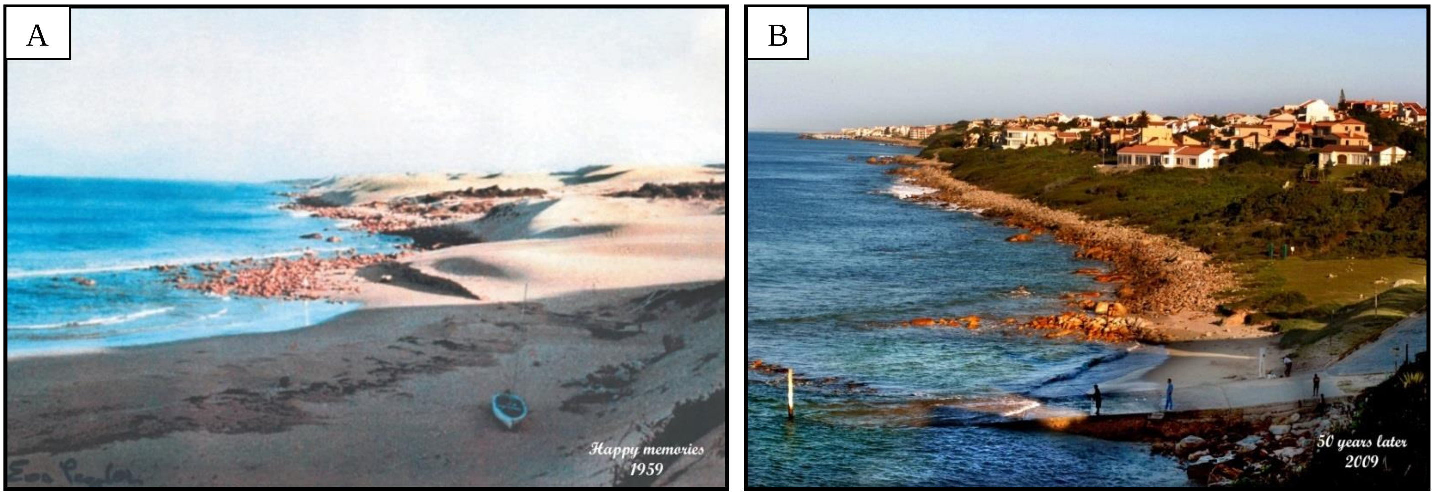


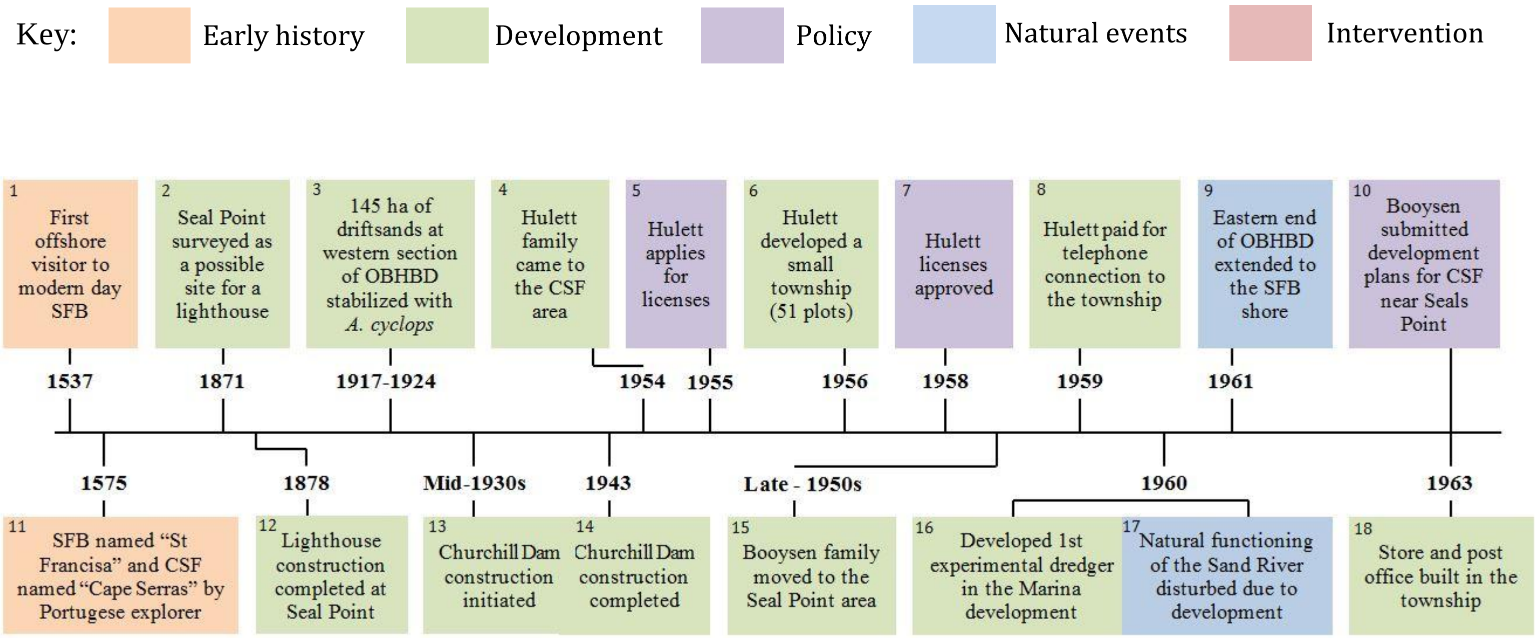
Figure 23: Santareme in 1959 [A] and 2009 [B] (Photo: Taylor, 1959 [A] and 2009 [B]) (14 in Figure 13)

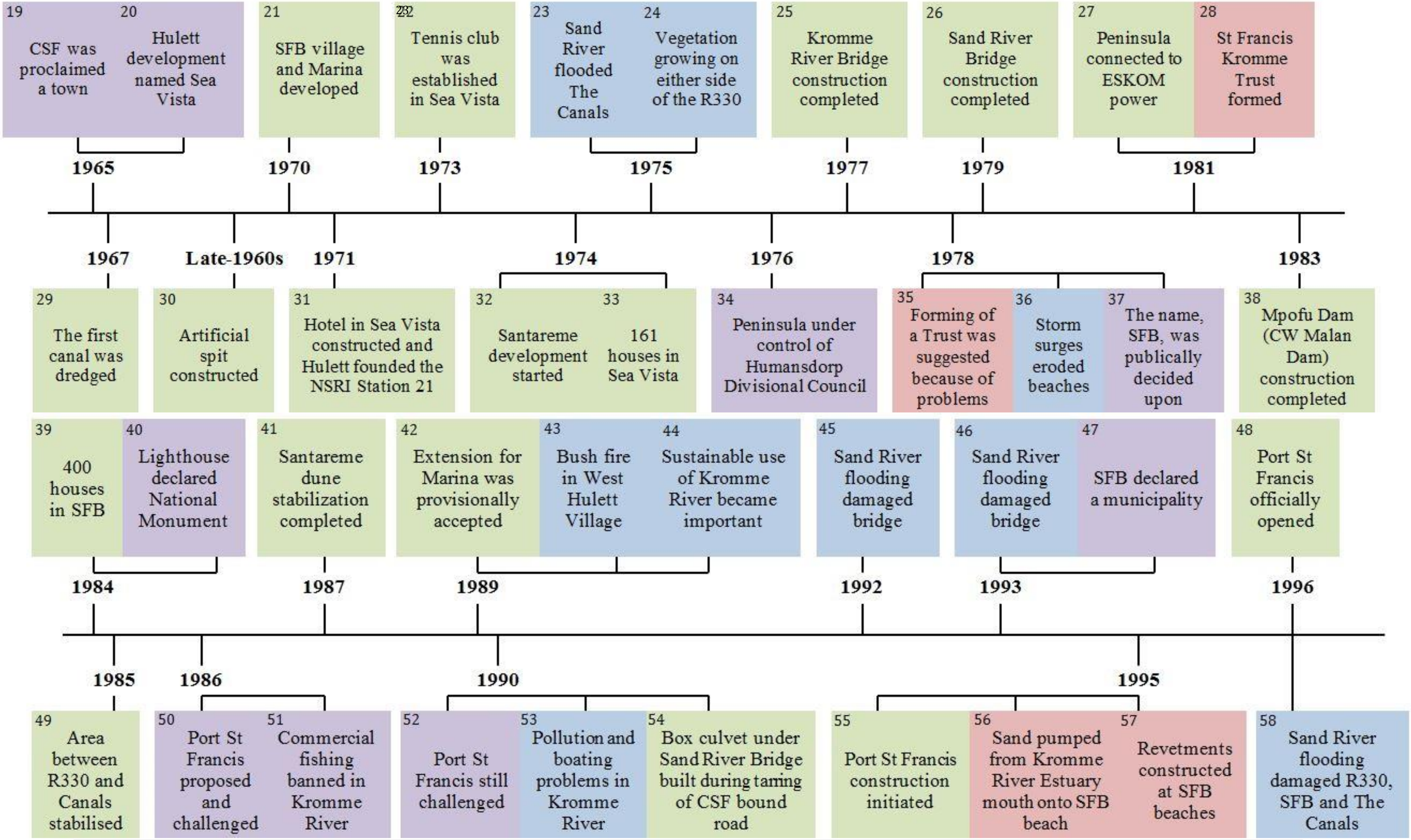
Figure 24: Cape St Francis beach in the 1980s [A] and in 2014 [B] (Photo: Taylor, n.d.[A]; Schroeder, 2014 [B]) (16 in Figure 13)

Figure 25: Flooding of Cape St Francis in 2012 (Photo: Cowling, 2012) (17 in Figure 13)

Some respondents supplied newspaper clippings which were amalgamated and these formed the majority of the media-reviewed timeline. It is important to note that not all the information regarding the newspaper clippings were provided and thus could not be referenced properly. Collected cuttings with no original references were referenced as a personal communication.

Activities and events highlighted by local stakeholders and newspaper articles were categorized into early history, development, policy and intervention methods. From 1950s to 1970s development was the most common activity (Figure 26). The frequency of natural disasters increased after the development phase with the first documented event occurring in 1975 when the Sand River flooded. Intervention activities were most prevalent from the mid-1990s onwards. Policies were initially linked to development but later became more associated with intervention methods. Numbering of timeline boxes is not chronological.




19
CSF was proclaimed a town
20
Hulett development named Sea Vista
21
SFB village and Marina developed
22
Tennis club was established in Sea Vista
23
Sand River flooded The Canals
24
Vegetation growing on either side of the R330
25
Kromme River Bridge construction completed
26
Sand River Bridge construction completed
27
Peninsula connected to ESKOM power
28
St Francis Kromme Trust formed
1965
1970
1973
1975
1977
1979
1981
1967
Late-1960s
1971
1974
1976
1978
1983
29
The first canal was dredged
30
Artificial spit constructed
31
Hotel in Sea Vista constructed and Hulett founded the NSRI Station 21
32
Santareme development started
33
161 houses in Sea Vista
34
Peninsula under control of Humansdorp Divisional Council
35
Forming of a Trust was suggested because of problems
36
Storm surges eroded beaches
37
The name, SFB, was publically decided upon
38
Mpofu Dam (CW Malan Dam) construction completed
39
400 houses in SFB
40
Lighthouse declared National Monument
41
Santareme dune stabilization completed
42
Extension for Marina was provisionally accepted
43
Bush fire in West Hulett Village
44
Sustainable use of Kromme River became important
45
Sand River flooding damaged bridge
46
Sand River flooding damaged bridge
47
SFB declared a municipality
48
Port St Francis officially opened
1984
1987
1989
1992
1993
1996
1985
1986
1990
1995
49
Area between R330 and Canals stabilised
50
Port St Francis proposed and challenged
51
Commercial fishing banned in Kromme River
52
Port St Francis still challenged
53
Pollution and boating problems in Kromme River
54
Box culvet under Sand River Bridge built during tarring of CSF bound road
55
Port St Francis construction initiated
56
Sand pumped from Kromme River Estuary mouth onto SFB beach
57
Revetments constructed at SFB beaches
58
Sand River flooding damaged R330, SFB and The Canals

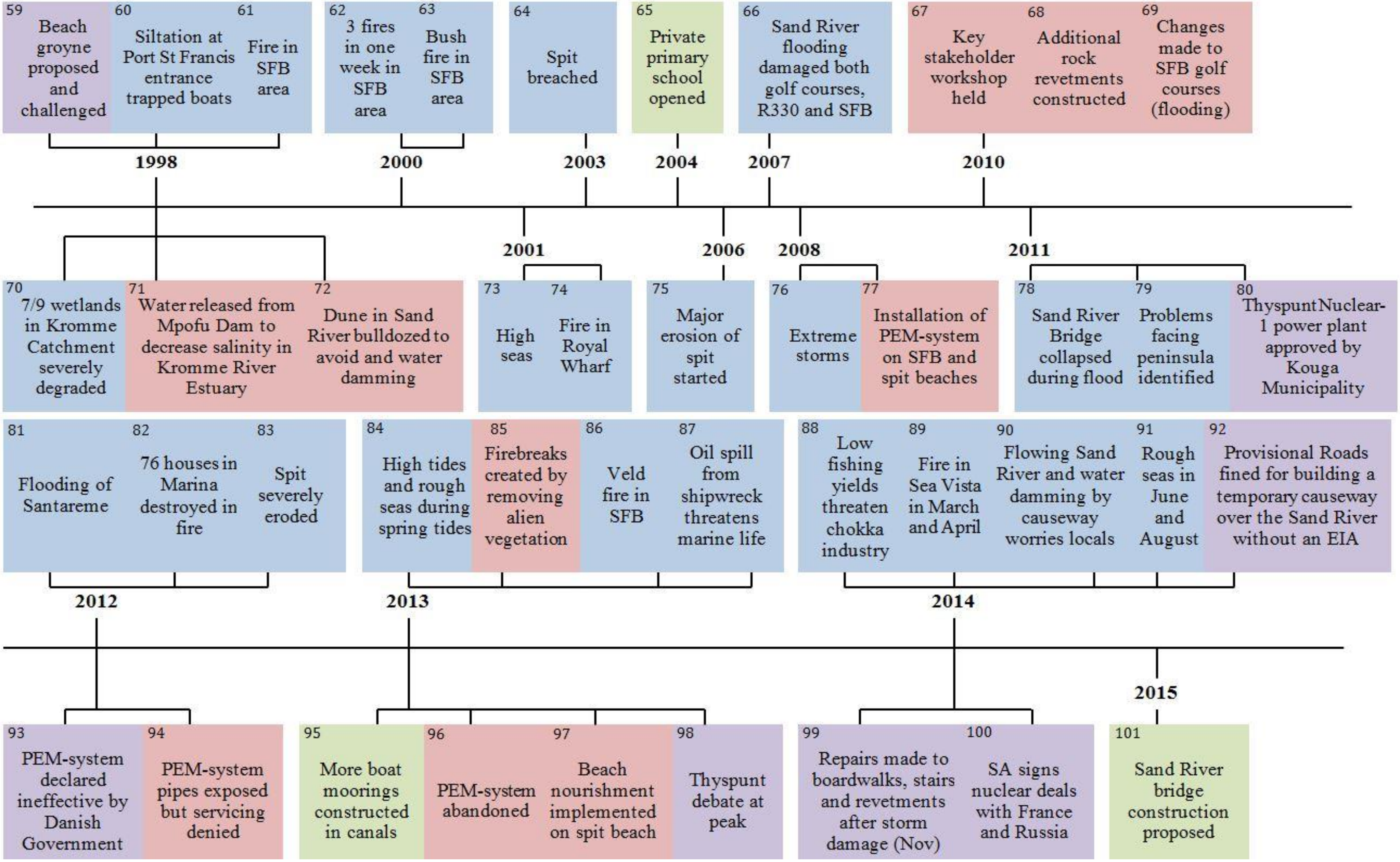


Figure 26: Media-reviewed historical timeline of the Cape St Francis/St Francis Bay peninsula

5.3. Field surveys of measurable selected features

5.3.1. Past and present beach width

The beach width of St Francis Bay and Cape St Francis has decreased from 1961 to present from the aerial images (Table 4). Both beaches receded by more than 200 meters; however the St Francis Bay beach receded by eight meters more. Nonetheless, the change became more evident in St Francis Bay than in Cape St Francis. In St Francis Bay the beach width was well over 200 meters in 1961 as compared to the present width of below 100 meters; while the beach width in Cape St Francis was near 400 meters or more in 1961 compared to the present beach width ranging from 100 to more than 200 meters.

Table 4: Beach width comparison from 1961 to 2011 at St Francis Bay and Cape St Francis beaches

<table>
<tr><th colspan="11">St Francis Bay</th></tr>
<tr><th colspan="5">1961</th><th colspan="4">2011</th><th rowspan="2">Beach difference (m)</th><th rowspan="2">Average difference (m)</th></tr>
<tr><th>Cross section</th><th>To vegetation</th><th>Cross section</th><th>To ocean</th><th>Total width</th><th>To vegetation</th><th>Cross section</th><th>To ocean</th><th>Total width</th></tr>
<tr><td>1</td><td>22</td><td>85</td><td>180</td><td>287</td><td>2</td><td>85</td><td>0</td><td>87</td><td>200</td><td rowspan="7">211</td></tr>
<tr><td>2</td><td>70</td><td>87</td><td>180</td><td>337</td><td>0</td><td>87</td><td>0</td><td>87</td><td>250</td></tr>
<tr><td>3</td><td>40</td><td>55</td><td>172</td><td>267</td><td>3</td><td>55</td><td>0</td><td>58</td><td>209</td></tr>
<tr><td>4</td><td>22</td><td>57</td><td>180</td><td>259</td><td>3</td><td>57</td><td>0</td><td>60</td><td>199</td></tr>
<tr><td>5</td><td>5</td><td>63</td><td>177</td><td>245</td><td>0</td><td>63</td><td>0</td><td>63</td><td>182</td></tr>
<tr><td>6</td><td>50</td><td>70</td><td>200</td><td>320</td><td>0</td><td>70</td><td>0</td><td>70</td><td>250</td></tr>
<tr><td>7</td><td>18</td><td>71</td><td>196</td><td>285</td><td>0</td><td>71</td><td>24</td><td>95</td><td>190</td></tr>
<tr><th colspan="11">Cape St Francis</th></tr>
<tr><th colspan="5">1961</th><th colspan="4">2011</th><th rowspan="2">Beach difference (m)</th><th rowspan="2">Average difference (m)</th></tr>
<tr><th>Cross section</th><th>To vegetation</th><th>Cross section</th><th>To ocean</th><th>Total width</th><th>To vegetation</th><th>Cross section</th><th>To ocean</th><th>Total width</th></tr>
<tr><td>1</td><td>120</td><td>143</td><td>122</td><td>384</td><td>46</td><td>143</td><td>0</td><td>189</td><td>196</td><td rowspan="8">203</td></tr>
<tr><td>2</td><td>56</td><td>101</td><td>126</td><td>283</td><td>22</td><td>101</td><td>7</td><td>130</td><td>153</td></tr>
<tr><td>3</td><td>95</td><td>122</td><td>169</td><td>386</td><td>35</td><td>122</td><td>14</td><td>171</td><td>215</td></tr>
<tr><td>4</td><td>83</td><td>186</td><td>149</td><td>418</td><td>6</td><td>186</td><td>0</td><td>192</td><td>226</td></tr>
<tr><td>5</td><td>17</td><td>189</td><td>193</td><td>399</td><td>7</td><td>189</td><td>0</td><td>196</td><td>203</td></tr>
<tr><td>6</td><td>35</td><td>183</td><td>188</td><td>406</td><td>0</td><td>183</td><td>40</td><td>223</td><td>183</td></tr>
<tr><td>7</td><td>10</td><td>192</td><td>230</td><td>432</td><td>1</td><td>192</td><td>10</td><td>203</td><td>229</td></tr>
<tr><td>8</td><td>27</td><td>209</td><td>205</td><td>441</td><td>4</td><td>209</td><td>10</td><td>223</td><td>218</td></tr>
</table>

5.3.2. Study sites

Beach surveys were conducted at the spit, St Francis Bay, Cape St Francis and the Shark Point Dunefield (Figure 27). These beach and dune surveys were done every three months over the surveying period. Important to note that the first set of surveys (October 2013) were done with a total station, whereas the other four sets of surveys were completed with a differential GPS (DGPS). Figure 27 shows the locality of the surveyed sites which consisted of five cross sections at the spit; seven at St Francis Bay and eight at Cape St Francis. Three cross sections and three longitudinal profiles were surveyed in the dunefield because of the time constraints associated with the equipment.

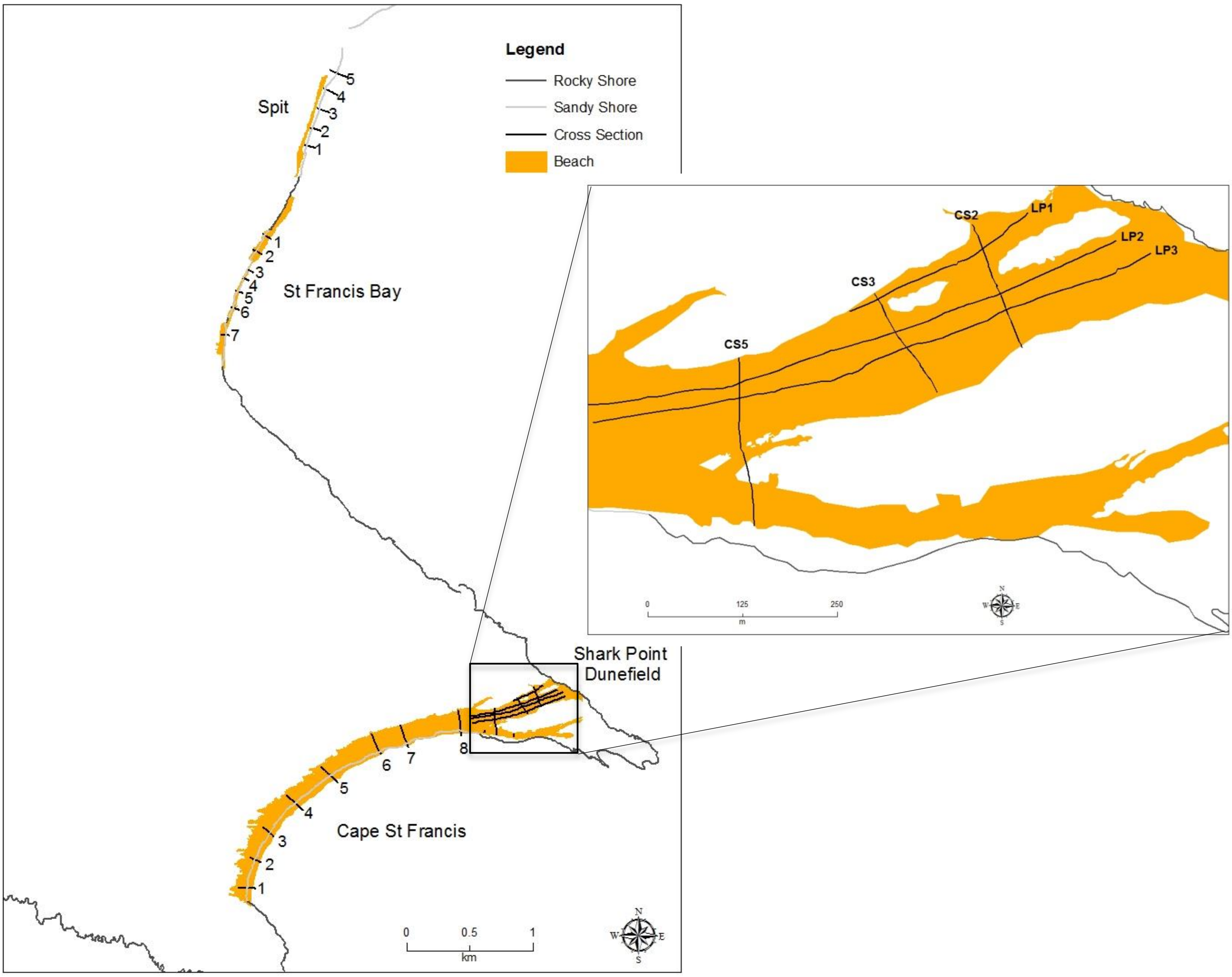


Figure 27: Study sites in St Francis Bay, Cape St Francis and the Shark Point Dunefield

5.3.3. Total station and differential GPS surveys

Figure 28 highlights two cross sections from each beach; one that represents the most change over the surveying period and one where changes were insignificant. Spit 5 shows the most change at the spit. The poor state of the spit was most evident in October 2013 as indicated by the short width and steep profile. The beach increased in width from ~ 30 meters to ~ 150 meters from October 2013 to July 2014. Spit 4 displayed the least observed change of the spit. There was also an increased beach width in this cross section. The elevation increased in July showing that deposition had occurred over most of the surveying period. In both spit 5 and spit 4 there was a decrease in beach width from July 2014 to October 2014. Over the surveying period morphological changes across the spit was slight, with the least change seen in cross section closest to the Kromme River Estuary (Appendix 2).

St Francis Bay beach was believed to be eroding more rapidly than Cape St Francis and so the site was of great concern to most residents. SFB 3 exemplified a morphological rapidly changing beach in St Francis Bay (Figure 28). Beach width depended on the spring high tide. Over the surveying period the beach width varied by ~ 30 m. Over three surveying periods (October 2013, January 2014 to April 2014) the beach experienced deposition. This trend continued from April to July 2014 whereby the beach reached its maximum width. The depositional period was followed by erosion, which removed approximately two meters of sand from the beach between July and October 2014 (indicated by the arrow). SFB 7 highlighted the least amount of change that took place in St Francis Bay. It was considered relatively stable with slight morphological changes and smaller changes in width. Where beach dunes are still present beach morphological changes are less drastic (SFB 1, 2 and 7) than where there are revetments (SFB 3, 4, 5 and 6) (Appendix 2).

In Cape St Francis the beach widths were double, and even triple, the size of the beach in St Francis Bay in some profiles (Appendix 2). CSF 5 highlighted the most change that occurred in Cape St Francis (Figure 28). CSF 7 and 8 also show noticeable morphological changes (Appendix 2). Morphological changes where dunes form, deform and potentially reform was clearly visible in the Cape St Francis cross sections. The width of the beach in CSF 5 also varied over the surveyed period like in St Francis Bay. CSF 1 showed the least amount of change. Similar morphological patterns and beach widths were observed in all repeated surveys. CSF 2 and 6 showed modest changes (Appendix 2). In October 2013 the beach width across all the cross section was the shortest.

The Shark Point Dunefield (which was connected to the Cape St Francis Beach) cross sections and longitudinal profiles are shown in Appendix 3 and Appendix 4. Little to no change was observed in the Shark Point Dunefield cross section 2, while dunes formed, deformed and reformed in the other two cross sections (Appendix 3). The most change was seen in cross section 5 which was closest to the Cape St Francis beach. The longitudinal profiles illustrate the movement across the dunefield highlighting how dunes form and deform within surveying periods (Appendix 4).

5.3.4. Climate variables

Local climate variables (temperature, rainfall, wind direction and speed) were identified over the entire surveying period and these could potentinally affect the field survey outcomes (Table 5). January was the hottest month with 24 degrees Celsius, whereas June was the coldest with ten degrees Celsius. The predominant wind direction consisted of Westerlies and the average wind speed varied between four and six and a half meters per second. April was the wettest month while September had the least rainfall.

Table 5: Climate variables that could have affected field survey outcomes

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
Average maximum temp.(°C)	19.9	20.7	21.5	24.3	22.9	21.6	20	20.3	18.9	18.1	18	19.1	19.1
Average minimum temp. (°C)	14.4	16.2	16.3	19.1	17.7	15.6	14.3	13.3	10.2	10.9	12.3	13.1	14.3
Total Rainfall (mm)	88.5	68	16.5	25	43.5	67.5	113	52.5	85.5	70.5	51.5	90.5	15.5
Average wind direction	WNW	W	W	W	W	W	W	W	NNW	WNW	NW	ENE	W
Average wind speed (m/s)	6	6	5.1	5	4.7	4.7	4.3	5.6	6.3	5.2	6.1	4.7	5.3

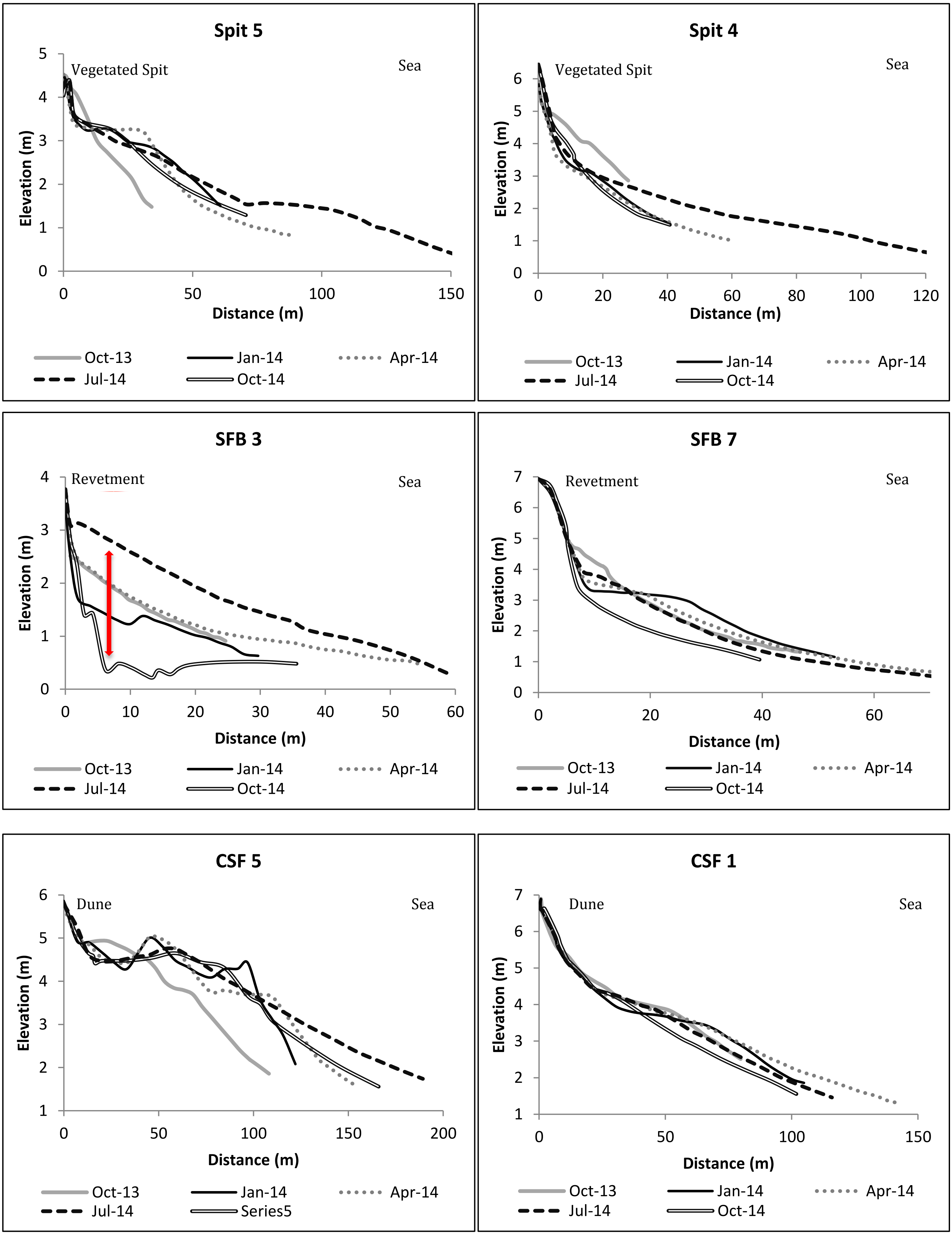


Figure 28: Cross-sections from the spit, St Francis Bay and Cape St Francis showing the most (left) and least (right) change over the surveying period

5.3.5. Volumetric calculations

The DGPS data was used to calculate the volume of the beaches (Table 6). The calculation highlight cut (+) and fill (-) periods. The spit had its highest depositional peak in July, however erosion occurred otherwise. In St Francis Bay deposition took place from January to July 2014, however the volume drastically decreased by more than 260 000 m^3. In Cape St Francis erosion mainly occurred in April. Sediment volume was gained in July, but lost by October 2014. In total more than 250 000 m^3 was lost. The Shark Point Dunefield experienced erosion throughout the surveying period.

Table 6: Volume calculations from beach and dune surveys

*survey October 2013 excluded due to equipment		+ erosion - deposition	
Site	Month	Volume (m^3)	Volume change (m^3)
Spit	January	581124.7	
	April	521066.9	60058
	July	603157.4	-82091
	October	594612.5	8545
St Francis Bay	January	784834.5	
	April	820644.0	-35810
	July	849672.2	-29028
	October	585796.0	263876
Cape St Francis	January	8666199	
	April	7926188	740011
	July	8238850	-312662
	October	7982502	256348
Shark Point Dunes	January	3419813	
	April	3342107	77706
	July	3328219	13888
	October	3312129	16090

5.3.6. PEM drainage poles

For the first time over the surveying period the PEM pipes became visible during the October 2014 survey. These pipes were located at the spit and St Francis Bay beaches (Figure 29). More pipes were seen in St Francis Bay than at the spit.

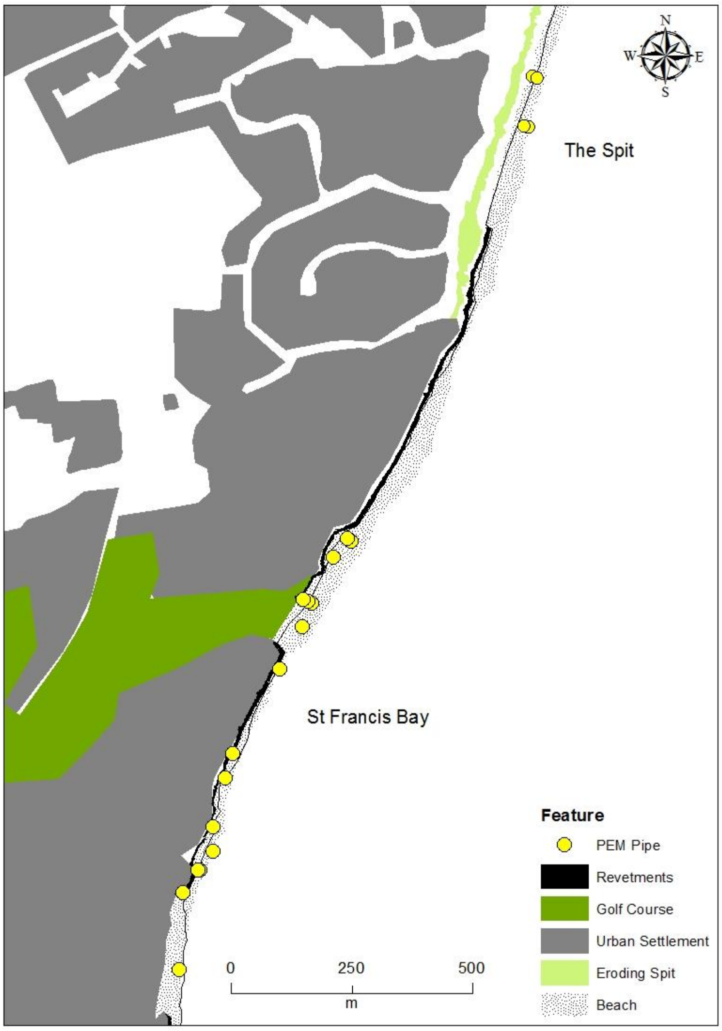


Figure 29: Positions of PEM installations in St Francis Bay and on the spit beach

5.3.7. Repeating survey 2007

From 2007 to 2014, deposition predominately occurred on the spit beach (Table 7). The highest level of deposition occurred near the Kromme River Estuary mouth. Minimal elevation change was observed at cross section 2 and the lower two points of cross section 1, with no elevation change seen at the second point of cross section 1. In St Francis Bay only erosion was observed in the resurveying. Cross sections 3 and 4 could not be resurveyed due to high water levels. The highest erosion levels were seen in the cross sections furthest from the spit (cross section 5, 6 and 7).

Table 7: DGPS survey comparisons of 2007 and 2014

+ erosion - deposition									
Spit					St Francis Bay				
Cross Section	Cumulative Distance (m)	Elevation (m)		Difference (m)	Cross Section	Cumulative Distance (m)	Elevation (m)		Difference (m)
		2007	2014				2007	2014	
1	0	2.7	2.34	0.36	1	0	2.36	1.54	0.82
	9	1.98	1.98	0		5	1.9	0.07	1.83
	18	1.29	1.59	-0.3		11	1.41	-0.26	1.67
2	0	2.67	2.75	-0.08		23	0.65	-0.73	1.39
	13	1.89	1.91	-0.02		29	0.5	-0.91	1.4
	23	1.32	1.25	0.07	2	0	2.72	0.77	1.95
3	0	2.9	2.46	0.43		8	2.01	0.26	1.75
	24	1.12	1.38	-0.27		19	1.11	-0.26	1.37
	37	0.61	0.99	-0.38		28	0.68	-0.5	1.18
	54	0.19	0.48	-0.29		44	0.16	-0.97	1.13
4	0	2.5	4.47	-2.24	5	0	0.61	-3.35	3.96
	22	1.53	2.15	-0.62		14	0.19	-3.38	3.57
	31	1.12	1.73	-0.61	6	0	1.34	-1.97	3.31
	45	0.77	1.32	-0.55		9	0.75	-2.91	3.66
5	0	1.67	3.08	-1.41		22	0.27	-3.15	3.42
	7	0.94	2.69	-1.75	7	0	3.11	-1.05	4.16
	12	0.65	2.44	-1.79		14	1.14	-2.18	3.32
	32	0.14	1.72	-1.58		33	0.26	-3.02	3.27
	58	-0.53	1.04	-1.58					

5.3.8. Laboratory Analysis

Sand samples taken from different areas on the peninsula as potential source and sink zones were analysed. The outcome of the particle size distribution was that 64 % of the sand samples fell below 250 µm, while 33 % fell below 125 µm (Appendix 5). This showed that the majority of the peninsula's sand consisted of medium grained sand, when compared to the sediment size distribution presented by Bird (2000: 96). The magnetic susceptibility was similar and extremely low for the potential source and sink sites to the extent that only low frequency measurements were performed. The results from the low frequency susceptibility readings (Appendix 5) suggested that either all sand samples were part of the same system or results could be deemed inconclusive as the sand samples were too coarse.

5.4. Conceptual model

A conceptual model was created from the available information gathered from literature. The results yielded from the various methods were used to indicate the flow of the peninsula's sediment movement (Figure 30). Potential pathways are shown in the conceptual model highlighting the flow and process moving the sediment from Oyster Bay to St Francis Bay and Cape St Francis. However through the stabilisation of driftsand and development, these pathways have lost their functionality. The conceptual model thus indicates which sediment pathway were impacted (red) or been less impacted (black) upon. The sediment flow model also illustrated which process was predominantly moving the sand at which section. It became evident that all the potential pathways have been stabilised over the period of development and thus only the Oyster Bay Headland Bypass Dunefield connected to the Sand River and the Kromme River, the Shark Point Dunefield and the ocean still play a vital role in the sediment supply to the St Francis Bay and Cape St Francis Bay beaches. The seasonal cycles were also represented in the conceptual model, which constitute of negative and positive feedback loops. Negative consists of sand being lost through storm surges (wave action), while positive consists of deposition through calmer ocean conditions.

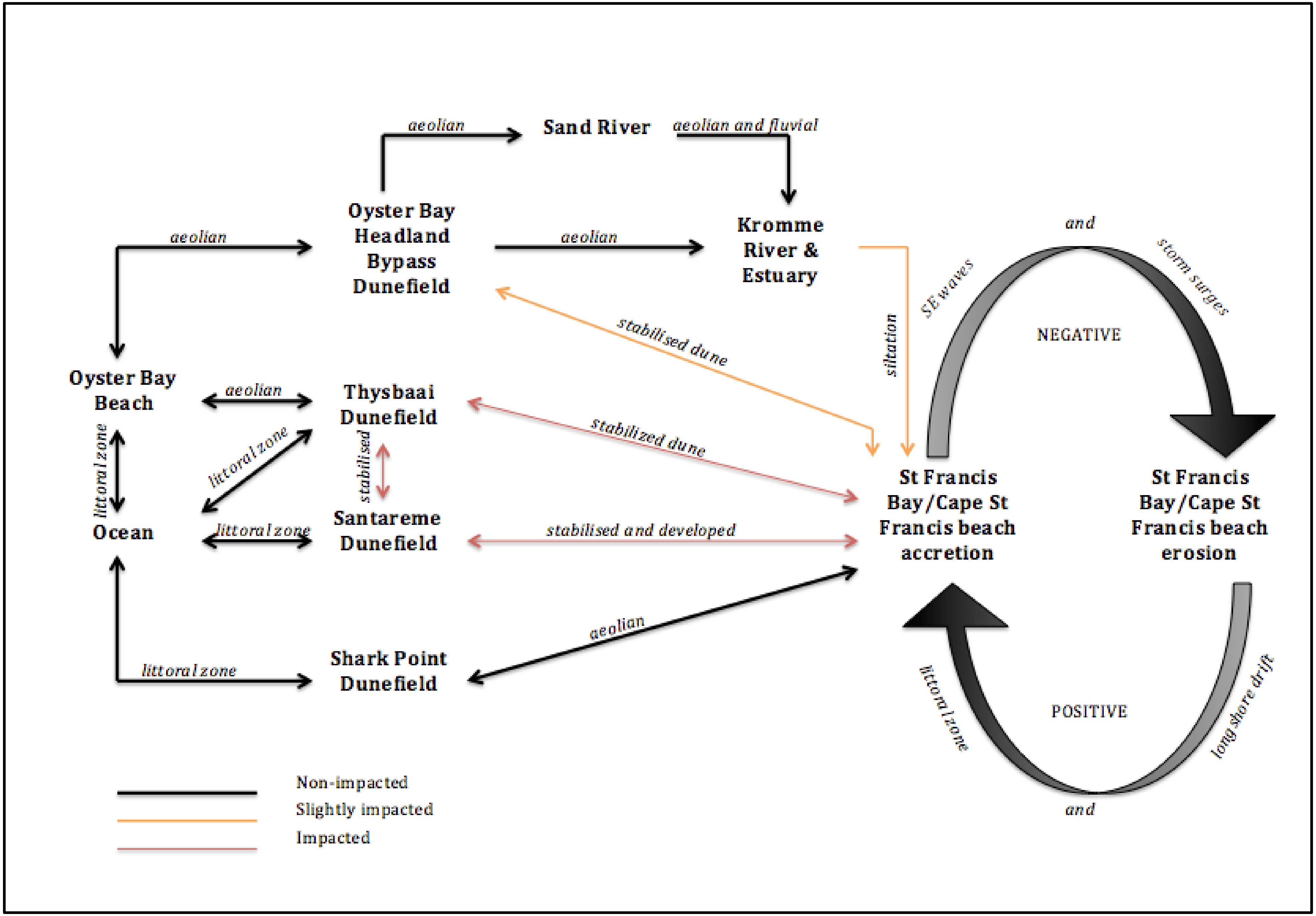


Figure 30: Conceptual model of the sediment transport across the peninsula

CHAPTER 6: Discussion

The aim of this research was to determine the historic and current coastal landscape changes present on the peninsula through the application of various methods and the effectiveness of the methods were evaluated. By combining the methods findings and relating them to existing literature, theories, and a framework a more holistic understanding of the study area over the 50-year period was created. Selected features of Figure 11were investigated and the discussion amalgamated the information gathered through the triangulated method.

Environmental degradation resulting from changes made to the natural landscape to allow for economic growth is not isolated to the peninsula, but has been seen globally and is commonly described in literature, e.g. Elliot (1998), Dean and Dalrymple, (2002), Small and Nicholls (2003), and Phillips and Jones (2006). Coastal processes, specifically aeolian and fluvial sediment transport, have been interrupted on the peninsula. This has led to property and infrastructural damages and potential threats to human lives (Figure 17; Figure 20; B in Figure 22; B in Figure 25).

Development on the peninsula started in the mid-1900s with three ‘boom phases’ observed (Figure 12, Table 3). The 1999 to 2009 period was regarded as the most significant development ‘boom phase’ (53 % area increase) and was attributed to the newly opened private primary school in 2004 (65 in Figure 26) and the St Francis Links Golfing Estate in 2006 (C2 in Figure 11). The St Francis Bay College encouraged more permanent residency in the area leading to increased property demand and expansion of the town. The St Francis Links Golfing Estate attracted both residents and tourists through estate living and golfing tournaments. Tourism is a dominant activity on the peninsula as seen by the numerous seaside resorts, accommodations and second homes. This characteristic is common to many coastal towns and has been observed elsewhere (Özyurt and Ergin, 2010). The second ‘boom phase’ was linked the film *The Endless Summer* (screened in 1966), which advertised the peninsula’s ‘perfect wave’. This has attracted and continues to attract numerous surfers from across the world to the area. The establishment of the unique St Francis Bay village and the ‘little Venice’ development known as The Canals further contributed to the appeal of the peninsula increasing tourism in the area and encouraging permanent and temporary migration to the area. The Santareme development also promoted St Francis Bay as a prime real estate area while the development of Port St Francis promoted employment opportunities (fisherman, port works and food industries).

Through detailed time series mapping, the interview process and the media-reviewed timeline it quickly became evident that St Francis Bay developed more rapidly than Cape St Francis Bay. The strive for economic growth was more apparent in St Francis Bay as seen by the number and evidence of early developments when compared to the more delayed development approach in Cape St Francis (A1, A3, A4, A5 in Figure 11; Figure 12; 4-8, 10, 15 in Figure 26). Rapid development was seen in St Francis Bay shortly after the arrival of the Hulett family, while the Booysen family only submitted development plans for Cape St Francis some years after their arrival (10 and 15 in Figure 26). The emphasis on development in St Francis Bay led to more frequent anthropogenic landscape changes and consequently resulted in more environmental degradation e.g. decreased dune area (Figure 12; Table 3), beach erosion (Figure 28; Table 7) and ecological issues in the Kromme River and estuary (Figure 14; 28, 35, 44, 53 in Figure 26). This is in contradiction to Cape St Francis where nature reserves were delineated during the development phases due to the conservation interests of the Booysen family. Nature reserves surround the development in the area (L in Figure 11), while there are fewer natural areas in St Francis Bay. The findings support previous findings of Lubke (1985) who stated that during the development of St Francis Bay, Cape St Francis was merely a campsite. Tourism influenced development in the early development phases of the peninsula. St Francis Bay attracted tourists who preferred a more luxurious getaway, whereas Cape St Francis was attractive to tourists who desired a modest retreat. This still holds true today with the noticeably different style and size of housing in the two towns. Coastal developments need to be protected and so natural features are ‘stabilised’.

All the peninsula dunefields were active and fully functioning prior to dune stabilisation on the peninsula with Rooikrans and Port Jackson Willow (Elkington, 2012). Dune stabilisation protected development from being inundated with sand. A strong relationship was observed between development growth and mobile dune loss through the time series analysis (Figure 12; Table 2). Although dune loss continued throughout the development process (Figure 12; Table 3), the largest loss (17 %) occurred after the second development ‘boom phase’ and the second highest loss followed the third development ‘boom phase’. This shows a lag effect between the time series maps. A total of 66 % of dune area was lost through stabilisation and development (Table 3). The media-reviewed timeline bridged the knowledge gap between the time-series analysis map. While the maps provide spatial and temporal patterns, the timeline provides context for these patterns.

By including the public participation aspect in the research the community members were able to express concerns and increases accountability. It was important to have a diverse set of participants due to their natural interest bias based on direct impacts experienced. All the participants from Sea Vista mentioned the constant flooding of houses in the area result from the aquifer below the development (10 in Figure 13), and the frequent fires experienced in the area (11 in Figure 13). The high water table of the aquifer meant that after prolonged rainfall (3 days) flooding is likely to take place. The Sea Vista development was thus inappropriately placed and more suitable locations should have been identified before development commenced. Many interview participants of St Francis Bay and Cape St Francis placed extensive blame on the Santareme development for the loss of the Santareme Dunefield and the resulting beach erosion. While this development contributed a significant percentage (8 %) to the loss of mobile dunefields, it must be noted that the majority of dune loss was directly linked to the stabilisation of driftsand through the introduction of alien invasive species (58 %). Despite this area, known as the Thatchfarm, being stabilised to protect the Santareme homes from sand deposition and blasting during strong winds, for this study there was a separation between dune loss through stabilised land and developed land. Nevertheless, the loss of this dunefield has had a tremendous impact on the sediment budget on the peninsula as a major source for the beaches was lost (McLachlan *et al.*, 1994). Tinley (1985), Illenberger and Burkinshaw (2008) and Elkington (2012) provide evidence of sand being transported from Oyster Bay (west) to St Francis Bay (east) via the headland bypass dunefields (Figure 30). Through the particle size distribution analysis it became evident that the sample size distribution of all potential source and sink zones are less than or equal to 250 μm (Appendix 5). More than half of the sand samples consisted of medium sand and further analysis through low magnetic frequency susceptibility indicated that all the magnetic readings consisted of extremely low readings (Appendix 5), suggesting that all the sand samples are from similar sources. This further supports past literature assertions that sand moves west to east, Oyster Bay to St Francis Bay. Beach nourishment has become a major problem in St Francis Bay and continual beach erosion was highlighted by the majority of interview participants due to the economic threat it presents.

Through the crowdsourcing/participatory approach this research established that wide beaches were found on the peninsula prior to intense development, when anthropogenic interferences to the sediment supply budget were unknown. Old photographs presented by interview participants further illustrated this. The assumption sourced from the participants was that St Francis Bay beach had eroded more than the Cape St Francis beach. Aerial image comparison was done from 1961 and 2011. The perception coincided with the beach width measured from the 1961 aerial images where the St Francis Bay beach was significantly wider than at present (Table 3). The 2011 aerial images show that both St Francis Bay and Cape St Francis beaches narrowed in a similar manner (Table 3). Therefore, the local stakeholders' assumption was incorrect and it proved necessary for an expert to investigate their claims. Nevertheless, the local stakeholders input into this research proved valuable and added a unique dimension to the project. Boak and Turner (2005) explained how shorelines could change by more than 100 meters over a longer temporal scale, such as 100 years. It is, therefore, remarkable that the peninsulas beaches decreased by ~ 200 meters in width in just 50 years. This is compared to the study by Lubke (1985) where a nine meter recession of the St Francis Bay main beach was observed between 1975 and 1982, as well as to the study by Illenberger and Burkinshaw (2008), who measured a 60 meter beach width change between 1975 and 1995. Beach erosion has, therefore, been a threat for decades and may be seen as one of the most significant threats to the area at present.

The artificial spit was a sensitive and dynamic feature that was impacted through human interference and thus management proved to be difficult, as was illustrated by Ciavola (1997) in the United Kingdom. Ciavola (1997) found a recreation value of spits, and this was also seen on the peninsula due to frequent beach visitors, as it was an extension of the St Francis Bay main beach. During the fieldwork component of this study periods of sediment deposition and erosion were observed, and between July and October 2014 all three beaches experienced erosion (Figure 25; Table 6: Column 4). This study, therefore, supports van Rijn's (2011) findings that beaches around the world experience periods of erosion and deposition. The artificial spit beach width increased after the soft defence approach of placing textile sand bags on the beach sections furthest from the Kromme River estuary. The increase in width was also observed for St Francis Bay. Bird (2000) explained how concave profiles are linked to erosive (receding) beaches and convex profiles are associated with depositional (more prograding) beaches. The profiles of the beaches, therefore, suggest that the artificial spit and St Francis Bay beaches were eroding, as illustrated by the linear to concave profiles.

This is in comparison to Cape St Francis where beaches were prograding, as illustrated by the convex profiles (Figure 25, Appendix 2). A steeper profile was also seen at the erosive beaches (Figure 28, Appendix 2).

The morphology of the St Francis Bay beach profiles were similar despite the differences in elevation and width (Figure 28; Appendix 2). After a strong storm, a common occurrence on coastlines that experience Westerlies (Bird, 200) (Table 5), all beaches experienced erosion. Besides the penininsula predominantly experiencing Westerlies there was no direct relationship observed between local climate variables (Table 5) and the field surveys. A two meter drop in elevation was seen in most of the October 2014 cross sections in St Francis Bay due to the storm (Figure 28; Appendix 2), exposing PEM poles at the spit and St Francis Bay beaches for the first time during the surveying period (Figure 29). The high water mark became the low water mark. Water touched the revetments at the St Francis Bay beach during low tide covering the entire beach in many sections. Erosion was, therefore, linked to storm intensity. The construction of the port resulted in the loss of the popular surfing site known as Bruces Beauties. A few interview respondents indicated that Bruces Beauties was functioning properly during this stormy period due to the storms southerly swells. In Cape St Francis the observation of rocks in the surf zone near the Shark Point Dunefield showed erosion had taken place. Throughout the beach surveys Cape St Francis had a more ‘natural’ look as beach dunes formed, deformed and reformed along the beach profiles (Figure 28; Appendix 2). Significant seasonal changes became evident over the survey period (October 2013 – October 2014). The textile sand bags provided a line of defence between the ocean and the spit. This was due to visible erosion observed in the surveyed profiles, particularly those furthest away from the Kromme River mouth (Figure 28, Appendix 2). A form of recovery was, therefore, evident from 2007 through which the spit had lost an estimated 33 % of the beach and dune sand, highlighted in a municipal document (2007). This soft approach proved effective to some degree and should be implemented on the St Francis Bay beaches as well. Potential reasons for the Cape St Francis beach appearing less impacted could be attributed to the protection by the headlands and it may also have its own longshore drift supply suggested by the volume readings.

The volume readings highlighted a similar trend of the spit and Cape St Francis beaches through which a period of erosion and followed by deposition had occurred (Table 5: Column 4). In comparison St Francis Bay had experienced deposition over most of the surveying period from October 2013 to July 2014 (Table 5: Column 4). However, the volume readings again highlight that erosion was prevalent at all the beaches after the stormy period between July and October 2014 (Table 5: Column 4). Wave action was, therefore, the dominant erosive driver on the beaches as was described by Bird (2000), Andrade and Ferreira (2006) and Huntley (2013).Through the beach nourishment intervention the artificial spit beach had lost significantly less sand than St Francis Bay and Cape St Francis. Although both St Francis Bay and Cape St Francis lost more than ~ 250 000 m^3 of beach sand, St Francis Bay lost slightly more (Table 5: Column 4). Anderson (2008) estimated a sand loss of ~ 40 000 m^3 over the surveying period between October 2006 to September 2007. A regime shift had occurred on the peninsula through human-induced changes to the landscape (sediment supply interruption – Figure 30) and as such a prevailing period of erosion was seen in St Francis Bay. The beach surveys and volume calculations were extremely useful to the study as it provided information regarding current (seasonal) changes to the peninsula. Field measurements were important in estimating sand movement. The incorporation of field measurements with GIS analysis was important in understanding historical and current environmental states.

During the interviews, participants mentioned that although 2007 beach erosion was severe; the main beach state as observed in 2014 after the storms seemed worse. Through ‘The Beach Trust’ it was possible to resurvey some of the DGPS points that were taken in that year. The resurveying became a crucial component to the study, as it would provide information regarding beach’s state in terms of its resilience and recovery. It would also indicate whether the PEM system installed in 2008 at the spit and St Francis Bay (Figure 29) could be regarded as successful. Through the media-reviewed timeline and the interviews it was noted that the PEM system had been declared as ineffective by the Danish Government and despite the argument by the installer Mr Jakobsen the system was not serviced when poles became exposed and was eventually abandoned in 2013. The outcome of the 2007 resurveying showed a period of deposition observed on the spit beaches (Table 7). However, this was not attributed to the PEM system, but rather to the textile sand bags placed on the artificial spit beach over the Christmas period of 2013. By comparison St Francis Bay continued to erode leaving the beach in a worsened state, which coincided with what frequent beach visitors pointed out. This shows that local stakeholders input was accurate. Albeit the beach surveying showed periods of deposition for the majority of the surveying period, erosion was the prevalent driving force and as such it was concluded that there was no recovery of the St Francis Bay beach.

The interviews and the media-reviewed timeline proved to be the most important sources amalgamated during the course of this study, which provided knowledge regarding ‘natural events’ that had occurred on the peninsula over the past 50 years. These ‘natural events’ were directly linked to the human-induced changes on the peninsula, particularly to the positioning of the tourism orientated coastal urban town. The pattern extracted from the timeline was that intervention methods are now the primary focus of the peninsula (28, 35, 56, 57, 67, 68, 69, 71, 72, 77, 85, 94, 96, 97 in Figure 26). The frequency of natural events increased on the peninsula post the main development decades (23, 24, 36, 43-46, 53, 58, 60-64, 66, 70, 73-76, 78, 79, 81-91 in Figure 26), particularly threatening St Francis Bay. This pattern was common worldwide as describe by Carpenter *et al.* (2006). The Canals development was inappropriately placed in the Sand Rivers natural path. As a result there has been continual infrastructural and monetary damage (3 and 4 in Figure 13; Figure 16, Figure 17; 23, 45, 46, 58, 66, 78 in Figure 26). The collapse of the Sand River Bridge led to the peninsula being cut off from the rest of South Africa for over a week, severely impacting residents’ lives. High magnitude floods have on a number of occasions resulted in the collapse of the bridge (Figure 17) and the erosion of the Sand River berm (designed to protect the Canal properties). After a prolonged rainfall period in 2012 natural damming took place behind the Santareme development (Thatchfarm) causing severe flooding when the smaller ‘dam’ breached (12 and 13 in Figure 13; A and B in Figure 21; 81 in Figure 26). This flood had major impacts on urban development for the area. The continual infrastructural damage highlights the importance of understanding a system before development should be allowed. It is for this reason that a hazard and disaster management plan should be implemented for the region. Bearing in mind the peninsula predominantly revolves around tourism, the ‘natural recurring events’ may ultimately impact on the tourism sector in the long term. The continual negative publicity through beach erosion and floods deters potential property owners and holidaymakers. Therefore, this study agreed with Richie (2004) whereby tourism can be badly impacted by disasters and hazards. The peninsula’s ecological system as well as the social system has become environmentally and economically fragile. Hazardous natural events prove to be expensive. This is applicable to the Cape St Francis/St Francis Bay peninsula through fire damage repairs to properties and the implementation of coastal defence methods to protect properties and infrastructure to enable continued tourism.

Only 7 years after the Mpofu Dam construction, siltation was publicly documented as a problem in the Kromme River estuary because of the negative impact on boating activities and fishing (1 in Figure 13; A and B in Figure 14; 38 and 53 in Figure 26). The lack of natural flooding has meant less sediment was removed from the estuary mouth. This has reduced the contribution of sand from this fluvial source to the artificial spit and St Francis Bay beaches. The lessened flow means estuarine currents are not as strong as ocean currents. This further reduces the amount of sediment moved from the estuary. Commercial fishing was banned in the Kromme River and estuary in 1986 and sustainable use of this water source was emphasized a few years later (44 and 51 in Figure 26). The estuary is one of the tourist attractions on the peninsula and the sedimentation negatively affected tourism because of the limited activities. However, a lot of damage to the ecosystem had already been done. The degradation of the Kromme River estuary is a typical example of estuary systems fragility to human activities. As a result of the sediment supply interruption The Canals property owners' greatest concern became a reality when the artificial spit was breached (6 in Figure 13; A and B in Figure 19; 64 in Figure 26) and three years later severe erosion continued. This remained to be a prominent issue in 2014 (91 in Figure 26). Beach nourishment was seen as the best intervention method after the groyne construction was challenged due to the high cost and lack of funds. Sand was pumped from the canal system and Kromme River estuary onto the artificial spit and the textile sand bags were placed in 2013 in preparation for the holiday season (Figure 31). The nourishment now has to be done anthropogenically because the sediment from the estuary is no longer removed naturally. In an attempt to reduce salinity levels and flush out sediment from the estuary water was released from Mpofu Dam in 1998 (71 in Figure 26). While positive outcomes were evident post-water release the salinity levels returned to the previous levels within two weeks.

Figure 31: Textile sand bags placed on the artificial spit furthest from the Kromme River estuary mouth (Photo: Miller, 2014)

In summary a unique and complex dynamic system that was fully functioning prior to the human-induced landscape changes was impacted upon and consequently resulted in more frequent 'natural events'. Through the development phases, dune stabilisation became a prevalent issue cutting off the beach nourishment supply, which led to the erosion of the beaches. Through the stabilisation process dunefields not only were significantly diminished but also led to the Santareme Dunefield to stabilise completely. Through the anthropogenic interference with the Sand River, an unpredictable and unmanageable system was created. This became particularly evident through the frequent flooding as well as the collapse of the Sand River Bridge, which caused isolation from the rest of South Africa. It was, therefore, important to acknowledge a link between the social and ecological systems and the combination of the desktop analysis, crowdsourcing/participatory approach and field measurements provided the link to understand the past, present and predictive future system. For that reason the DPSIR framework (Figure 6) was applied to summarize what Drivers-Pressures-States-Impacts-and-Responses the peninsula had dealt with over the past 50 years to provide an improved understanding of the area (Table 8). The use of this DPSIR framework may provide a starting point for environmental managers in municipal governments and or agencies to begin addressing or tackling some of the localised socio-economic and environmental issues. Table 8 provides a concise and user-friendly representation of the main finding of this research. By using this tabular format the usefulness of the information is shown and insight into the problems and causes are simply stated. This also allows comparisons to be made with other similar studies which have made use of the same DPSIR framework, as done by Palmer *et al*. (2011).

Table 8: DPSIR framework in the Cape St Francis/St Francis Bay peninsula

Cape St Francis/St Francis Bay Framework Examples				
Drivers	*Pressure*	*State*	*Impact*	*Response*
Population size increase	Altered landscape	Less dunefields; unpredictable Sand River	Beach erosion; tourism; flooding of Sand River and bridge collapse	Revetments and beach nourishment; textile sand bags; berm
Land cover change	Alien invasive species	Biodiversity decrease	Habitat loss	Removal of aliens
Farmlands	Dam construction	Siltation of Kromme River; wetland Loss	Cannot Boat, tourism; pollution	Boating banned or unable to do it
GDP growth (Tourism)	Commercial fishing	Fish population decrease	Smaller fishing yield	Commercial fishing banned

Constraints and solutions

Constraints associated with each objective are discussed along with the solutions that were implemented.

Mapping of coastal landscape features

The image quality of the older images was often poor and it was sometimes difficult to delineate features, therefore, time frames that corresponded with good quality images were chosen.

Figure 32: Local fishermen providing information to field assistants

Investigating coastal landscape change

During field surveys inquisitive locals or visitors would ask questions regarding the research and many would contribute their own opinions (Figure 32). While this proved incredibly useful in most cases and good contacts were made, the surveying was hampered which put pressure on the author because of the equipment limitations, as discussed under *field surveys*.

Interviewees were so kind as to share old newspaper clippings from newspapers of the peninsula. However, some of the scans sent through unfortunately could not be read entirely or at all. If words were identified and there was no other media about the topic, the phrase was ‘Googled’ in an attempt to learn more about the event.

Field surveys

1. Human error: Minimal training of the DGPS (replacement);
2. Hardware: DGPS battery life (most limited factors);
3. Software: Malfunctioning total station in January 2014 and a corrupted DGPS geodatabase (points quadrupled); and
4. Logistics/physical constraints: Short surveying period (low tide window too short), beach width (Cape St Francis has a larger beach, therefore, more time-consuming), and surveying markers removed (by visitors in St Francis Bay) or destroyed (assumed sand blasting in Cape St Francis (Figure 33).

Figure 33: Broken pole from Cape St Francis wind

Constraints were successfully overcome during the course of this research through the further training received, manual deletion of quadrupled points, surveying of upper reaches of the beach in Cape St Francis during non-low tide times, small red marks on revetments allowed locality of cross-sections to be identified in St Francis Bay, and local memory (frequent beach visitors) helped identify cross sections at Cape St Francis along with bearing photos taken which also helped with locality.

Future research

As a result of this research some future research suggestions were concluded that would benefit the community of the Cape St Francis/St Francis Bay community. These are as follows:

Beach surveys

This research has shown that a large amount of sand was removed from the St Francis Bay beach between the surveying periods (July to October 2014) as a result of an extremely erosive storm. This had resulted in a two meter drop in most places. The peninsula’s residents were extremely concerned, as October 2014 was regarded as the worst state the main beach has ever seen in. It would therefore be beneficial to repeat this study of beach surveying, particularly those taken of the St Francis Bay beach where erosion was more distinctive, to investigate beach recovery. This would not only provide new knowledge regarding its resilience but also insight into its state of equilibrium.

Monitoring and management

Many residents have expressed a concern regarding the siltation and salinity of the Kromme River and its estuary. The recreational activities (for example boating) were hindered through the siltation process, as large sediment banks formed. This was regarded as disconcerting as it would affect the tourism sector in the long term and seeing as the Cape St Francis/St Francis Bay peninsula strongly revolves around the tourism sector the implications may be drastic. A study should be done of the Kromme River’s siltation and salinity. This could be established through turbidity readings to determine the clarity of the water thus providing an indication of the siltation problem; whilst pH measurements would indicate the salinity of the water. Perhaps flow readings should be taken along the Kromme River to determine where flow stops. The Churchill and Mpofu Dam would also need to be included in this study, as these have significantly impacted the flow of the river.

Socio -ecological impact study

It may be extremely useful to determine the socio-ecological value of hard and soft artificial defensive structures. The textile sand bags seemed to have been successful at the spit and as such, should be implemented at St Francis Bay in association with the rock revetments. An investigation of the public’s perception should be done regarding hard structures such as groynes. A study was conducted in England through Tunstall and Penning-Rowsell (1998) whereby beach visitors were asked about defence structures. The outcome was that most visitors would rather see hard structures than permit beach erosion; as such a similar study could be done at St Francis Bay where beach erosion was found to be major threat, which may ultimately have a negative impact on tourism. It would also be extremely useful to assess the willingness of the property owners to pay for the coastal defence structures as there is no governmental funding available.

Suitable disaster and hazard management plan

The peninsula has been prone to flooding as well as bush fire issues and thus an effective disaster and hazard management plan should be put into place. This was not found to be in existence at this point in time and as a result a study should be done in order to bridge this knowledge gap. There was no information regarding flood lines data (for example 10 year or 100 year flood) of the peninsula. The study should also take into account the broader context of climate change, which suggests the possibility of more frequent and extreme events along with unusual climatic patterns.

CHAPTER 7: Conclusion

The Cape St Francis/St Francis Bay peninsula encountered numerous human-induced landscape changes that led to frequently occurring natural events that threatened property, infrastructural development and human life. Coastal landscape change occurred in the form of the stabilisation of driftsand through alien invasive species and urban development. Throughout this 50-year development period a transformation was observed whereby a little fishing village was altered into a popular urbanized coastal tourism destination and as such the tourism sector plays a vital role to the peninsula's economic sector. The aim of this research was to identify and map landscape features and changes over the last 50 years on the Cape St Francis/St Francis Bay peninsula. An inter-disciplinary approach was successfully used to achieve the objectives of this study.

The starting point for the research involved the identification and mapping of landscape features of the study area through a desktop analysis using GIS and ground-truthing, achieving objective one. This research has shown a relationship between urban development and dune area loss, as the development area increased, mobile dunes area decreased. Continual development occurred on the peninsula with a considerable amount of development taking place during the 1900s, as was the global trend described by Ellis *et al.* (2010). However, the majority of development (53 %) happened during 1999 to 2009. The continual development although appearing in so-called 'boom phases' resulted in an overall 66 % dune loss. This has impacted significantly on the sediment budget and thus on the sediment flow from Oyster Bay to St Francis Bay. A notable result from this research was that out of the 66 % in dune area loss, 58 % was lost through the introduction of alien invasive species, while only eight percent was lost directly to the urban development.

In order to get a perspective on the location and type of changes that had occurred, a crowdsourcing/participatory GIS approach using interviews with local residents was employed. It proved to be an invaluable source of information, providing context specific area information to support the desktop mapping and to fill in gaps between mapped years. Through this approach a vast amount of knowledge was sourced along with old photographs and newspaper clippings. This method allowed community members to voice their concerns, while contributing to scientific research. One of the major concerns of the peninsula's community was the ongoing beach erosion of the St Francis Bay main beach. The outcome of the interviews and the media-reviewed timeline was that after the development phases the peninsula experienced frequent natural events, which led to the adaptation of the community through intervention and policy implementations. This approach therefore provided significant knowledge regarding coastal landscape change, achieving objective two.

Objective three was successfully achieved through the beach and dune surveying in order to determine current (seasonal) changes of the peninsula. The outcome of the beach surveying was that deposition was the dominant process until July 2014. This depositional period was connected to the soft defence method (the textile sand bags and sand pumped from the Kromme River estuary) implemented on the artificial spit beach. However, erosion occurred between July and October 2014 on the Cape St Francis/St Francis Bay peninsula’s beaches. Community members had expressed their concern with regards to the St Francis Bay main beach after the storm hit in August/September 2014. Rightfully so as an enormous decrease in elevation was seen (a two meter drop) at St Francis Bay. A relationship between changes in sandy morphology was linked to sea level rise, as the low water mark touched the revetments after the severe storm. A survey was repeated from 2007 to determine the effectiveness of the PEM pipes and whether the spit and St Francis Bay beaches were on a downward erosion spiral or whether beach resilience and recovery was in sight. The outcome of this resurveying was that the textile sand bags proved to be effective at the spit, however severe erosion was still observed at St Francis Bay (with a four meter drop in elevation furthest from the spit). Thus the PEM system was believed to be ineffective. The spit and St Francis Bay beaches were regarded as the impacted study sites; while Cape St Francis although considered as pristine, was regarded as the less-impacted site where dunes formed, deformed and reformed providing a more natural look. Despite the natural look of the Cape St Francis beach erosion happened at a similar rate to the St Francis Bay beach. This was in contradiction to the perception of the local stakeholders’ showing the need for expert review of their perceptions.

Through the historic and current (seasonal) landscape changes that the peninsula had to endure resulting from the human-induced landscape changes, more frequent natural events have occurred. These natural events ranged from flooding to debris flows and from the stabilisation of driftsand to beach nourishment. As a result many properties, infrastructural development and human life are at risk. The Sand River flooding and bridge collapse have immensely affected the peninsula, as it had caused isolation in 2011; and this may cause a negative impact on the tourism sector. The breaching of the natural damming behind the

Santareme development resulted in severe flooding in 2012 causing immense development and infrastructural damages. Through this study it became evident that natural events occurred mostly in the St Francis Bay/Santareme area, while Cape St Francis seemed to be relatively protected from the natural events. The St Francis Bay community therefore had to come up with intervention methods and policies to combat beach erosion through the installation of rock revetments, beach nourishment (dredging), PEM system, and now textile sand bags. It is likely that the reason why Cape St Francis experienced less environmental problems may be connected to the development being placed further away from the shoreline and being surrounded by nature reserves, with relatively intact ecosystems and associated services. Figure 34 showed how the area could have looked like prior to the development phase, while also highlighting that the frontline of properties in St Francis Bay and The Channels fall within the 100 meter mark from the high water mark.

The results of this study were viewed through the DPSIR framework, which was applied in order to better understand how the system worked as a whole. Through this framework the issues related directly to the peninsula could be understood on a broader scale. As a result the peninsula's drivers, pressures, states, impacts and responses were highlighted, which explained the socioeconomic and ecological relationships that were found on the peninsula. Essentially this may be utilized to aid the management and future planning of the peninsula, and as such achieved objective four.

This study did not attempt to cover all the systems and features present on the peninsula as it primarily focused on the perceptions and concerns that were voiced by the local community and as such focused on the historic coastal landscape changes and the current loss in sand nourishment for the peninsula's beaches. This study will contribute to the body of literature (Tinley, 1986; Lubke, 1985; McLachlan *et al.*, 1994; Illenberger and Burkinshaw, 2008, La Cock and Burikinshaw, 1996; Anderson, 2008; Elkington, 2012; and Schroeder, 2012) that is associated with the Cape St Francis/St Francis Bay peninsula in that new knowledge was presented. Through the mastery of the methods, coastal landscape changes were presented, through the various (inter-disciplinary) approach and their results yielded form each, over the 50-year developing period. The constraints that occurred during the study were successfully overcome and the way forward has been presented through the future research suggestions. A quote by John F. Kennedy (1963) stated: "*Change is the law of life. And those who look only to the past or the present are certain to miss the future"*, thus long-term adaptive management strategies need to be put in place in order to find a state of equilibrium whereby a balance is found between the socioeconomic and ecological factors by learning from the past and moving forward, while taking global climate change (particularly sea level rise) into consideration for the future.

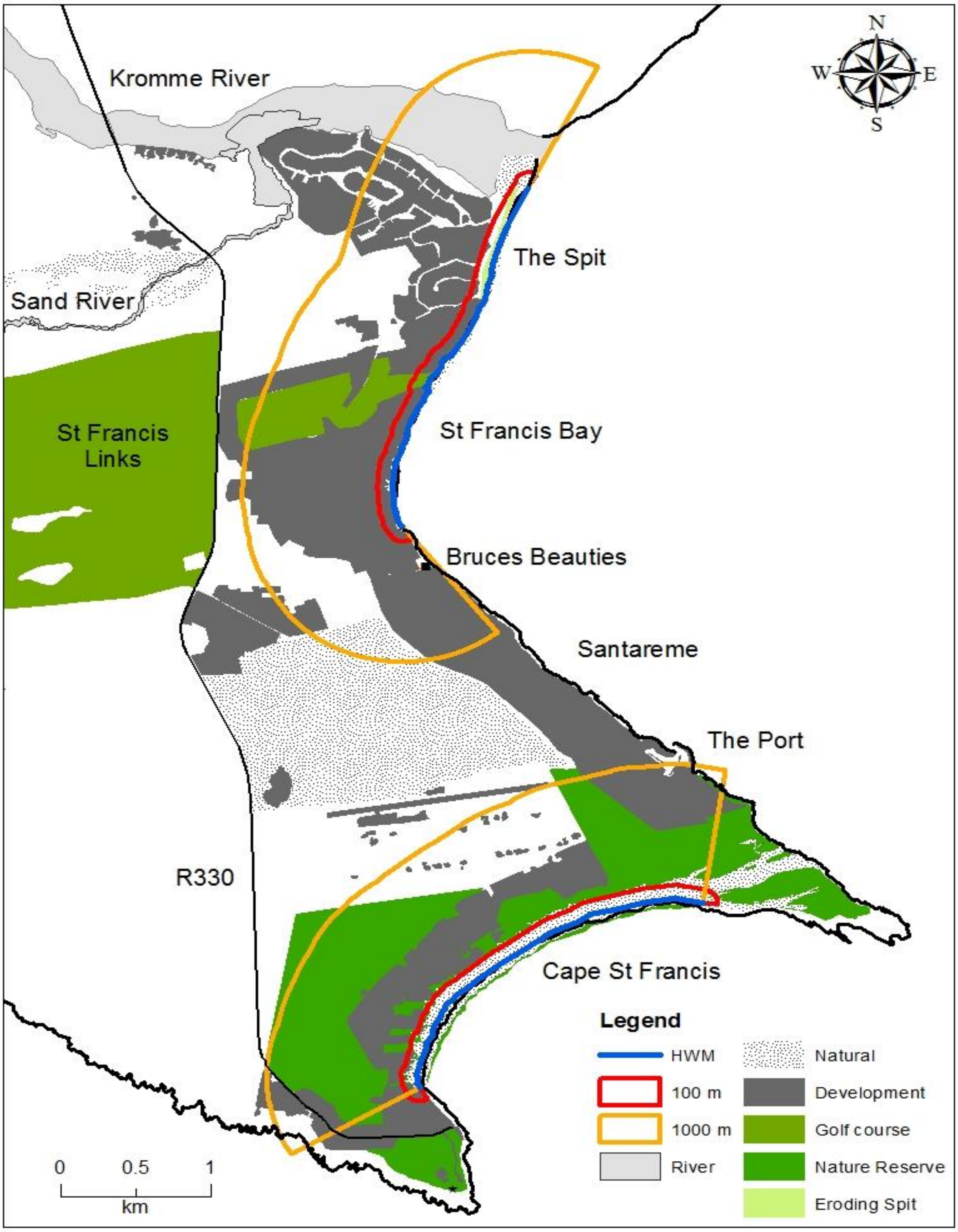


Figure 34: ICMA zonation on the Cape St Francis/St Francis Bay peninsula

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Appendix

1. Questionnaire

Cape St Francis/St Francis Bay Questionnaire

Daniel Schroeder
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Rhodes University
Geography Department
Cell: +27-82-5111-139
E-mail: dan.schroeder88@gmail.com
Supervisor: Ms Gillian McGregor: g.k.mcgregor@ru.ac.za

Background

I am a Geography Master's student at Rhodes University investigating landscape features and geomorphological processes on the Cape St Francis/St Francis Bay peninsula. The area has had to deal with a range of problems in the last 20 years varying from floods and debris flows to erosion of the beach front. Some of these problems might be 'natural', while others are the result of 'human interference' which then impact on the natural processes. The main natural landscape features of the peninsula are: rocky and sandy shores, Headland Bypass Dunefield, the Kromme River and its estuary, the Sand River, wetlands, the Sea Vista aquifer, and freshwater springs. Human-made features include: urban settlement, infrastructure development, The Port, The Marina, drainage ditches, an artificial Spit, The St Francis Links Golf Course, the proposed Thyspunt nuclear power station, and alien vegetated stabilised land. All information will remain anonymous and confidential. If you have any further questions regarding this survey, or my research, please do not hesitate to contact me on the details given above.

Question 1

Please indicate the relevant age bracket that you fall into:

Age:	*18-25*	*25-35*	*35-50*	*50-65*	*>65*

Question 2

Time associated with Cape St Francis/St Francis Bay:

Status:	*Resident*	*Regular Visitor*	*Occasional Visitor*	*Other*

If other please specify: ____

Regular visitor: every other month
Occasional visitor: app. once a year

Please specify how long your association is with Cape St Francis/St Francis Bay:

____

Question 3

Place of Residence:

Area:	*St Francis Bay*	*The Marina/Canal*	*Santareme*	*Sea Vista*	*Cape St Francis*	*Oyster Bay*

If anywhere else please specify: ____

Have you always resided in this area?

Yes	*No*

If *No*, please specify where else you have stayed:____

____

Question 4

Do you own the property?

Yes	*No*

If *No*, do you always return to the same place: __________________________

Question 5

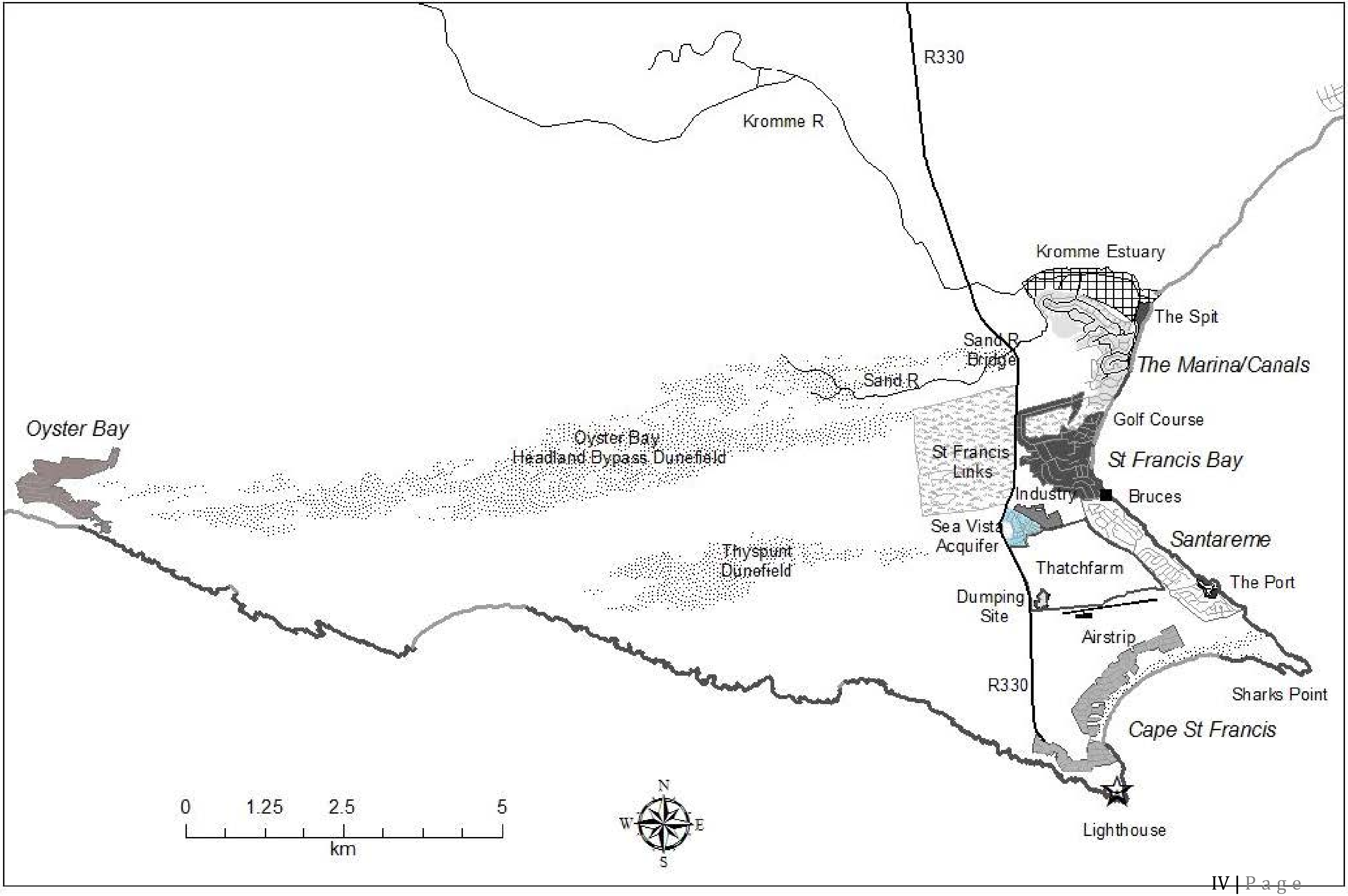
Occupation: ________________________________

Question 6

Please indicate (for example: by circling) on the map ‘places of interest’ in the context of this study that you know of. These may include environmental and social issues such as soil erosion, flooding, and the collapse of infrastructure, or areas that may have been rehabilitated. If you know a specific street affected, please name the street address in the space below. For every locality feature you have identified allocate a time period or date.

If you are interested in the research and/or would like to find out more about my Masters once it is completed or would like to attend a workshop for further discussion about this research, please provide your contact details:

Landscape Features and Processes of the Cape St Francis/St Francis Bay Peninsula



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The Marina

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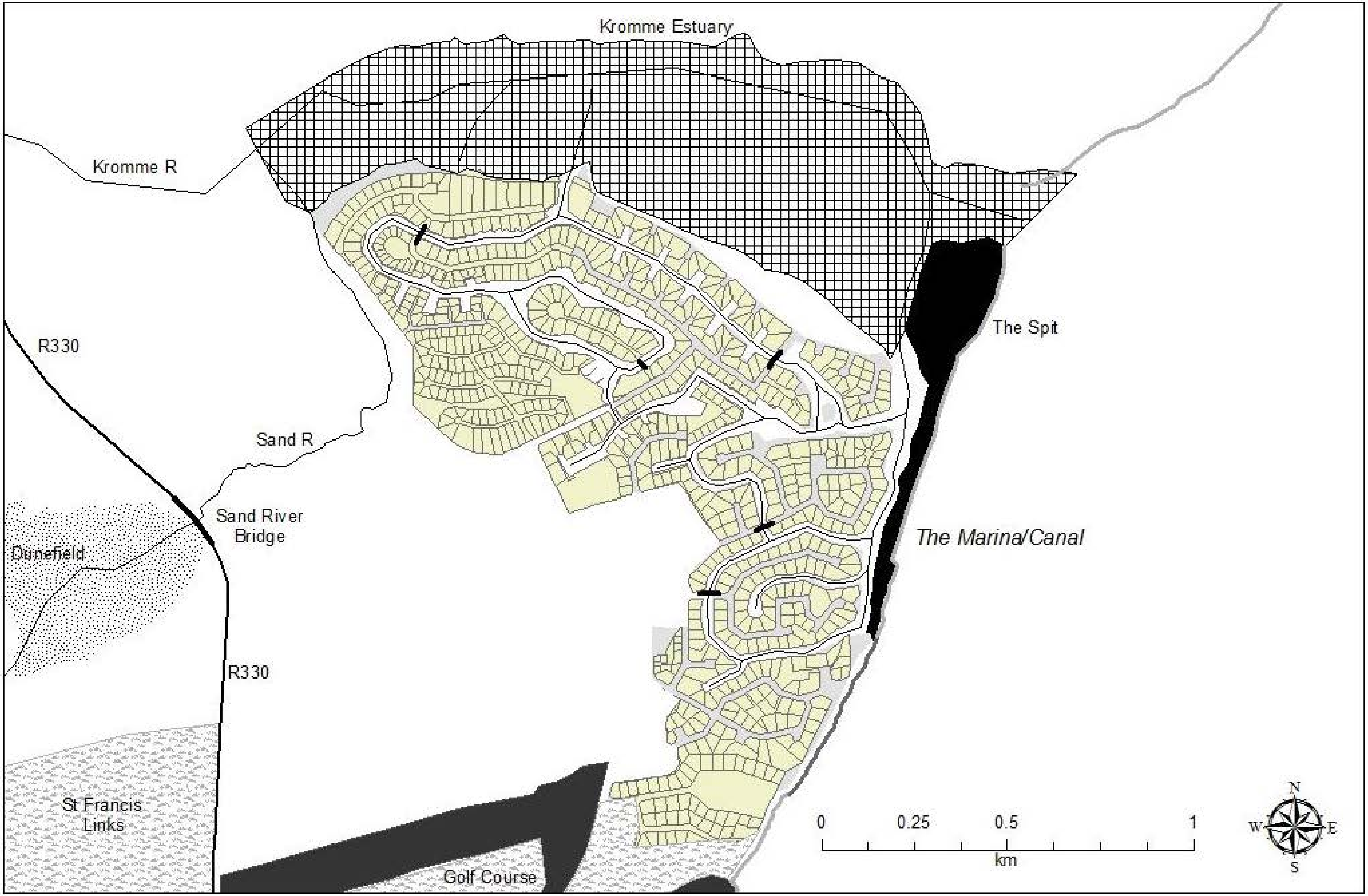

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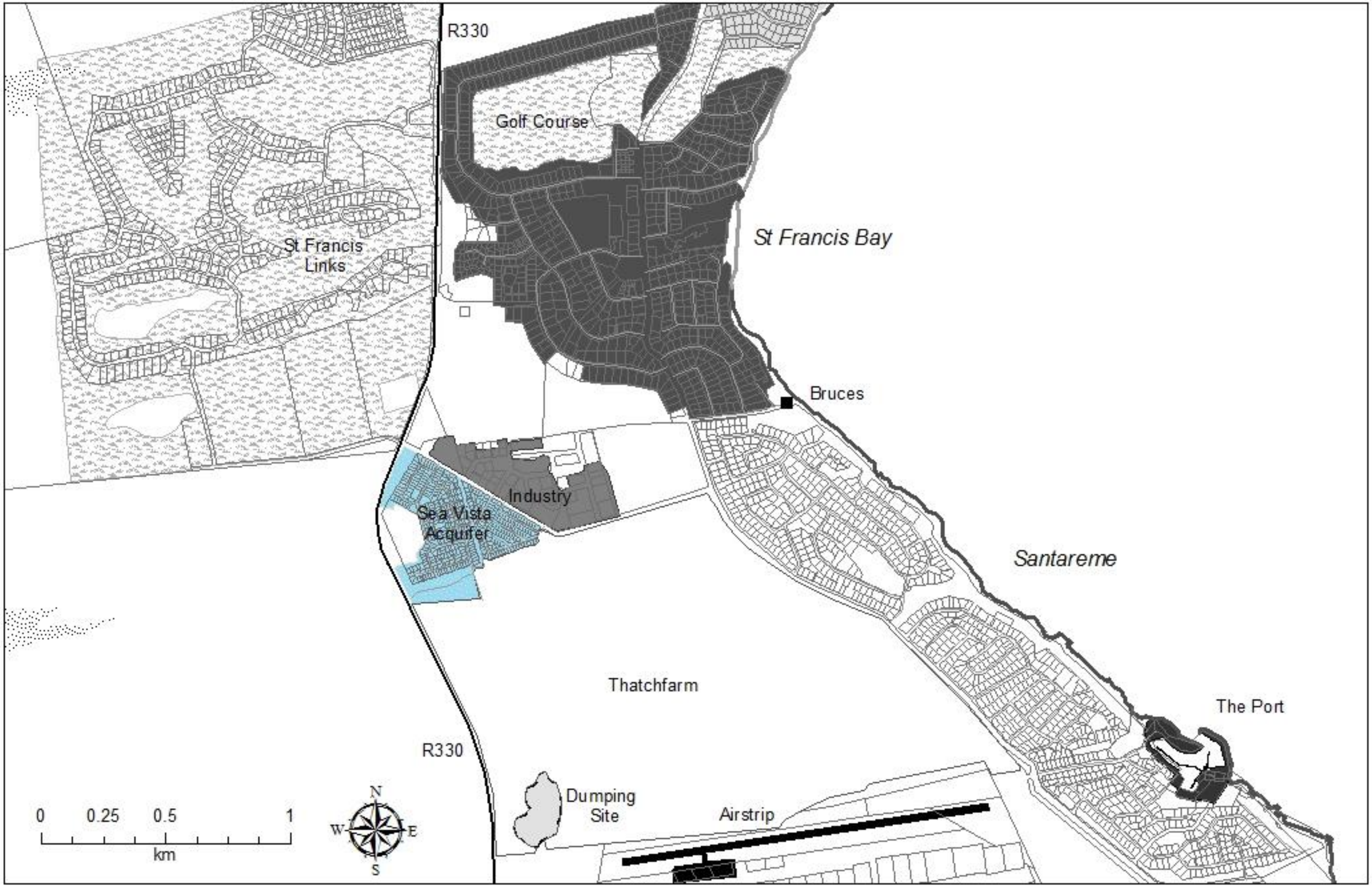
St Francis Bay and Santareme



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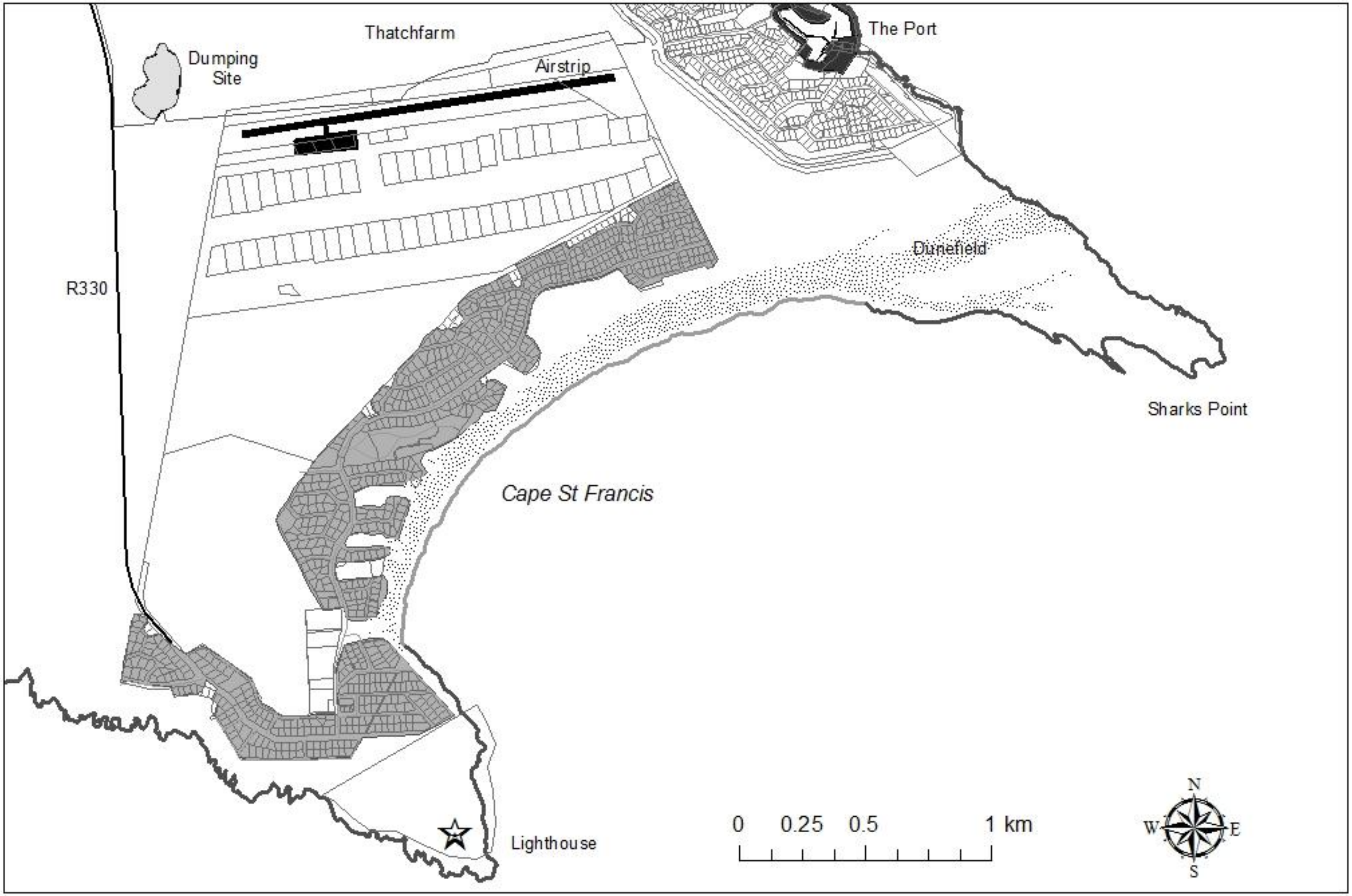
Cape St Francis



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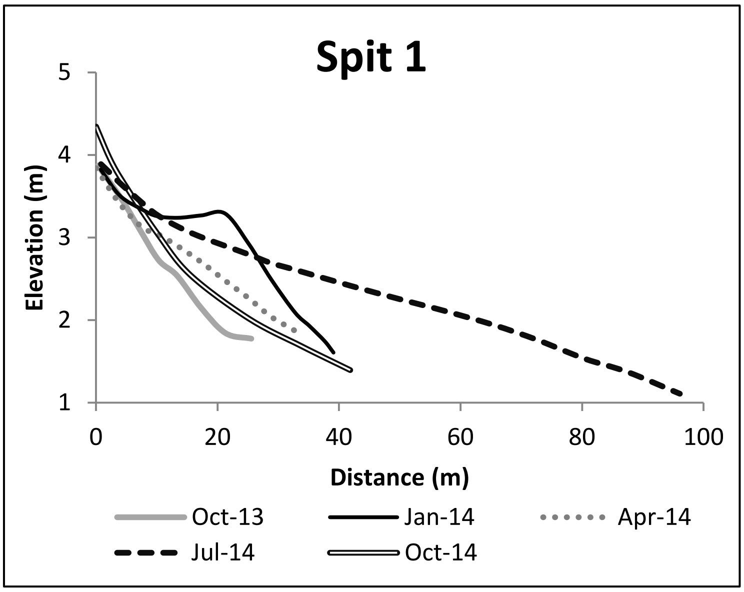
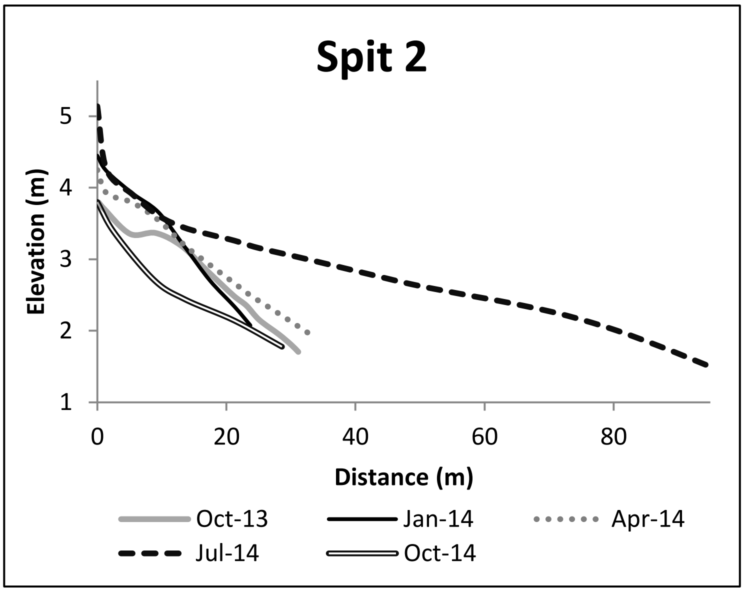
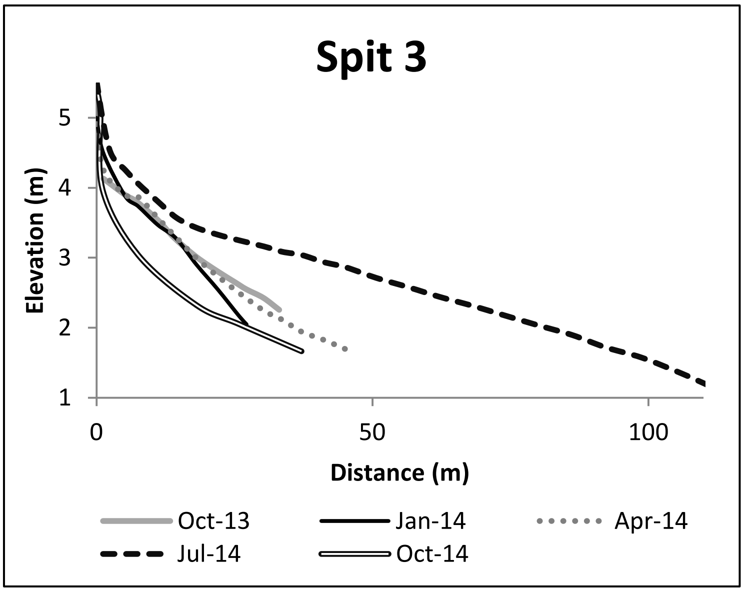
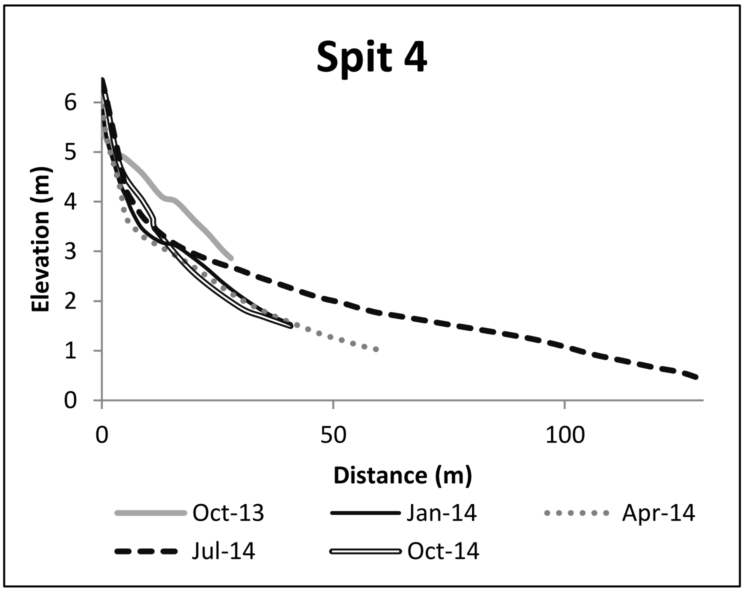
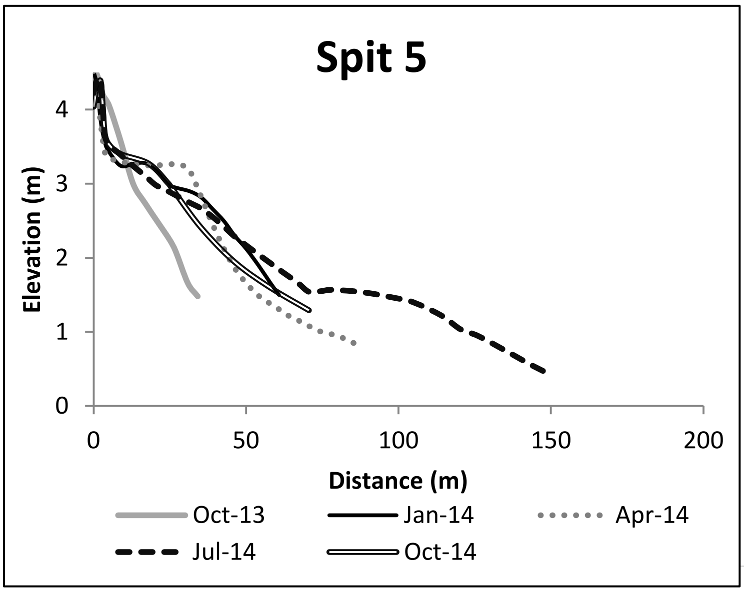
2. Beach surveys (cross section)

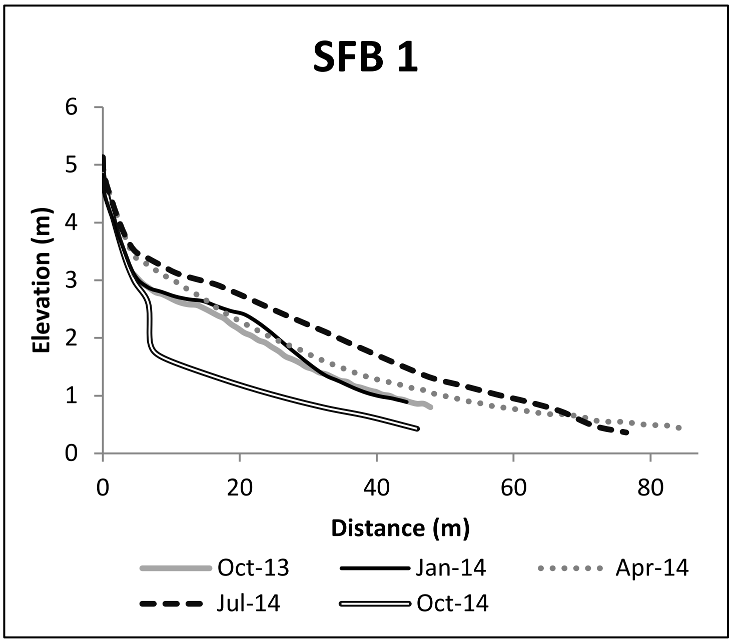








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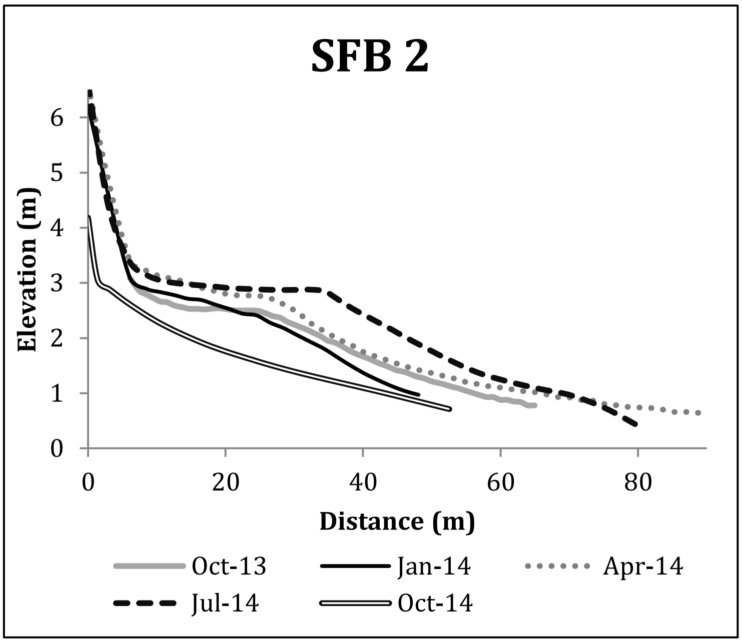
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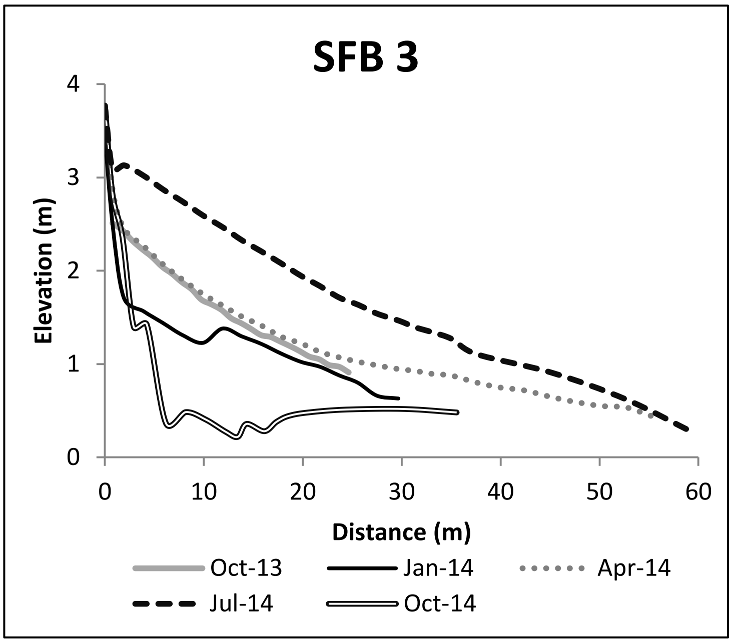
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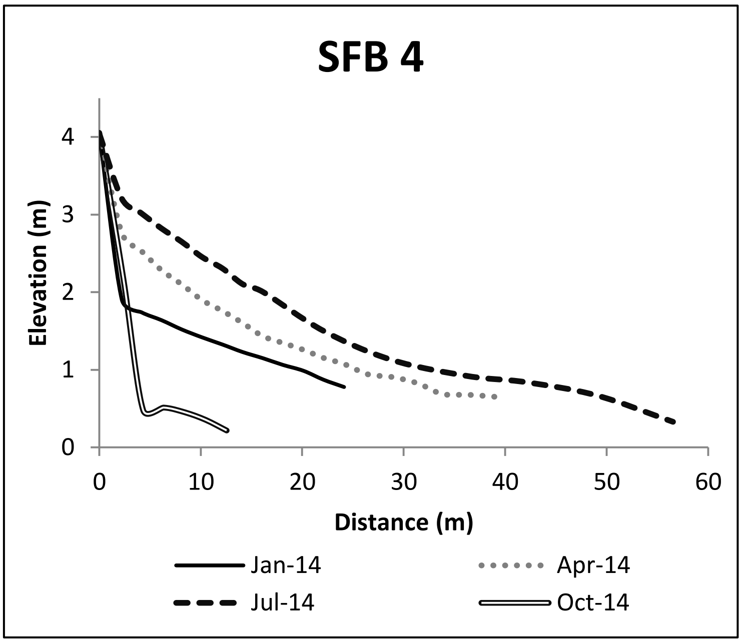
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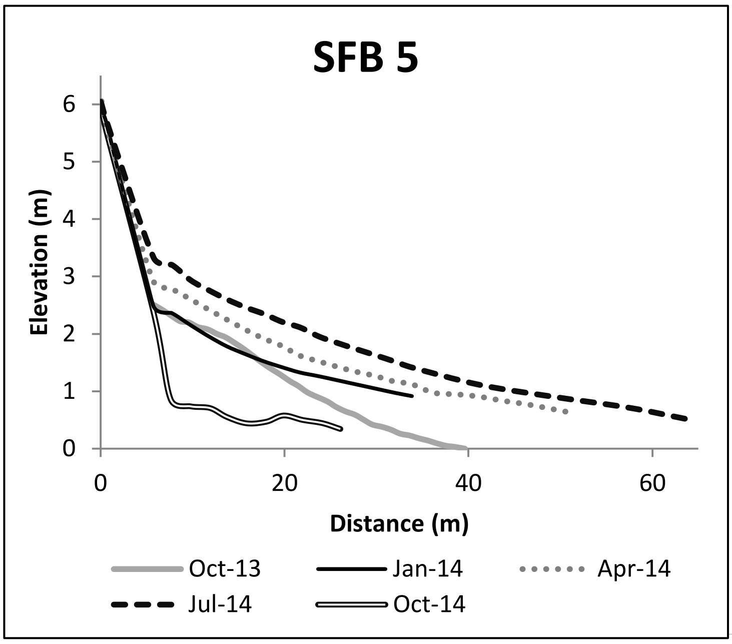
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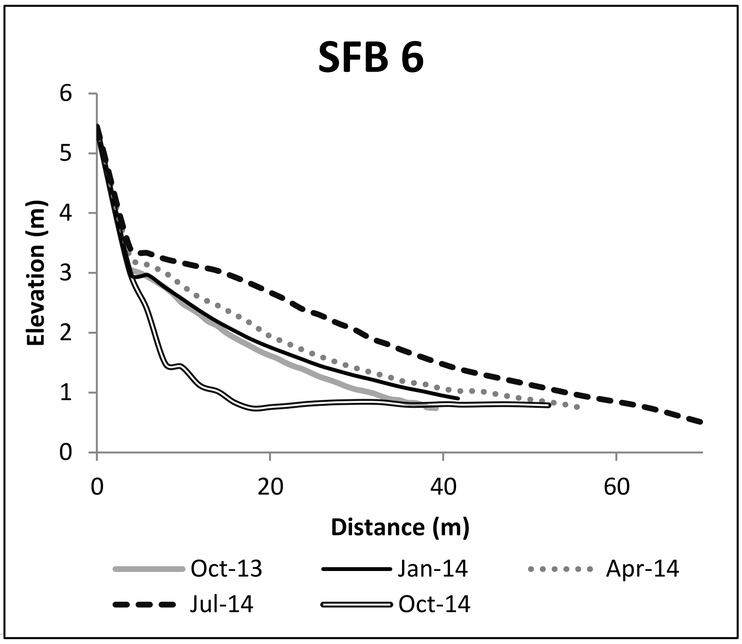
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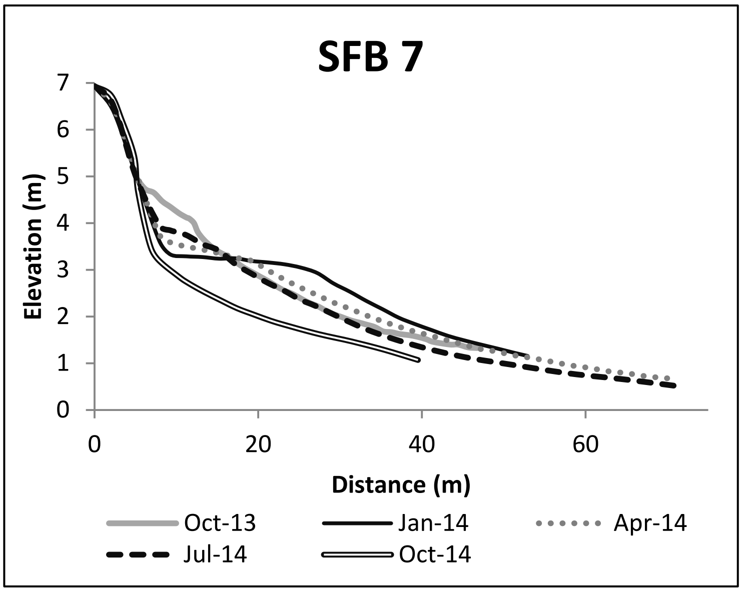
Appendix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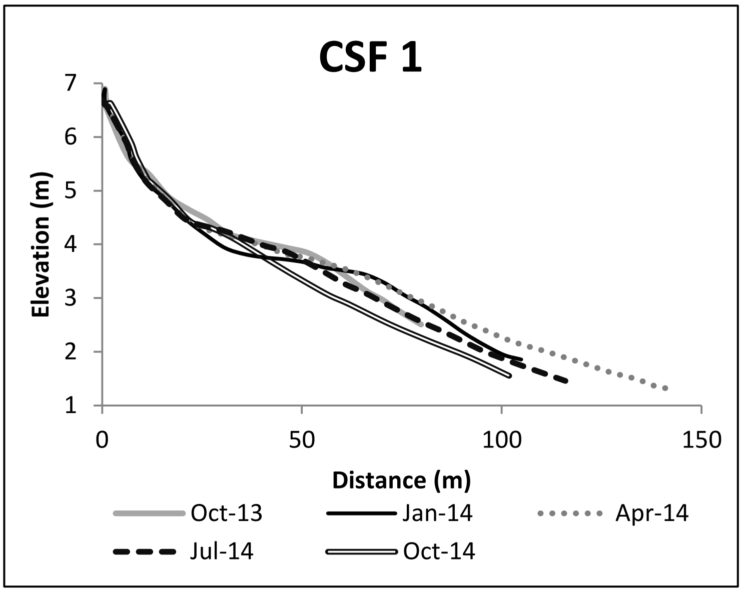
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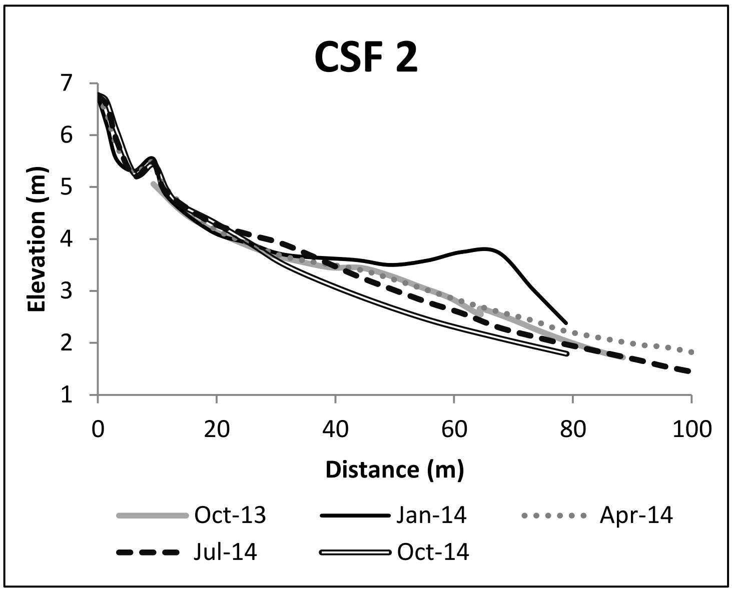
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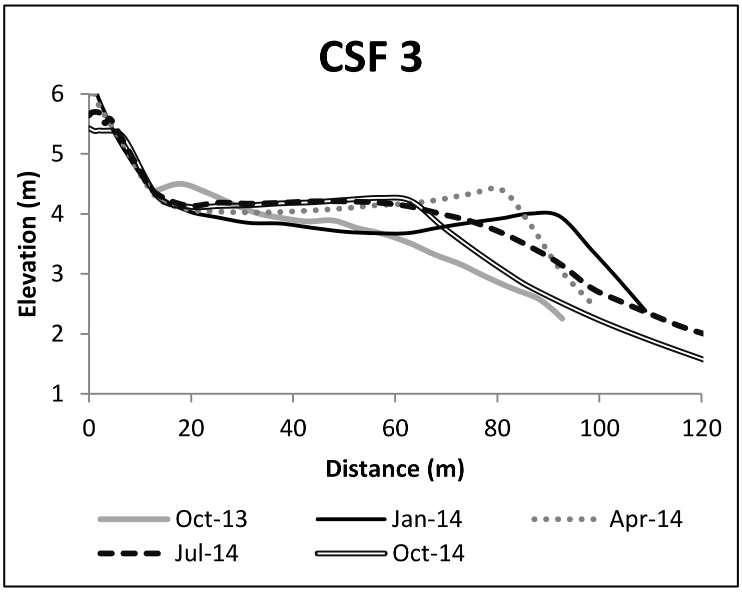
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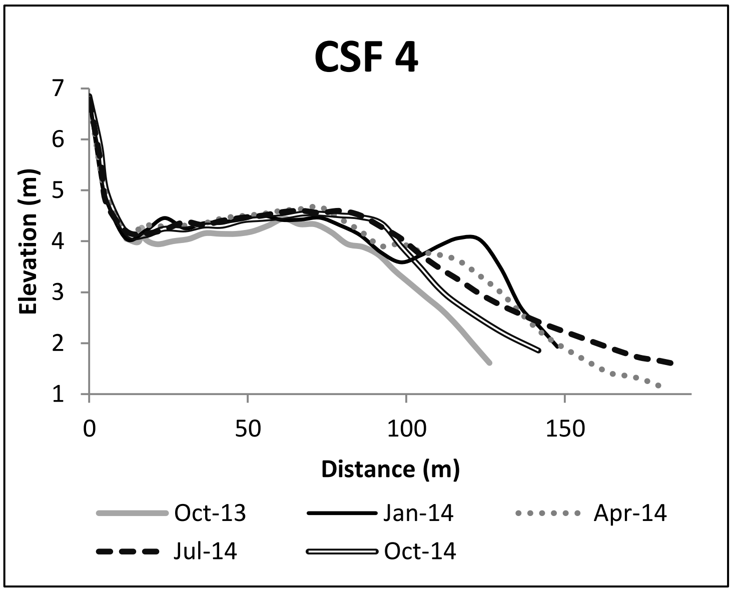
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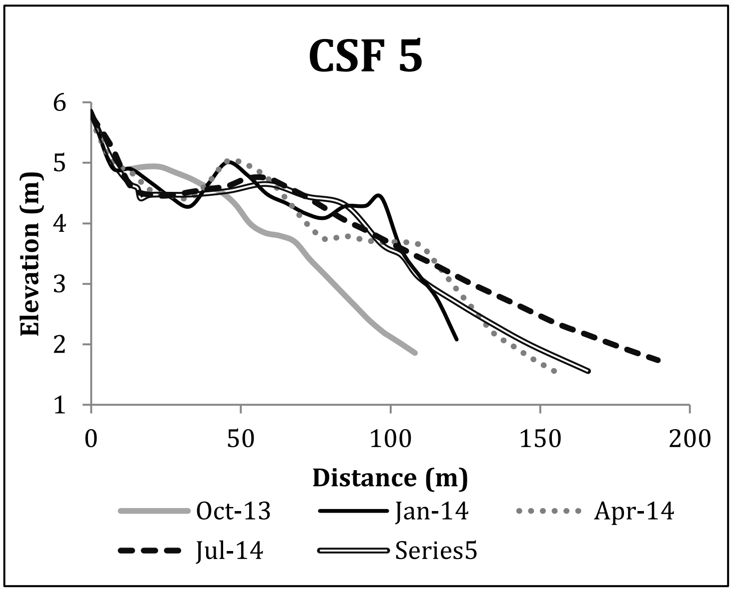

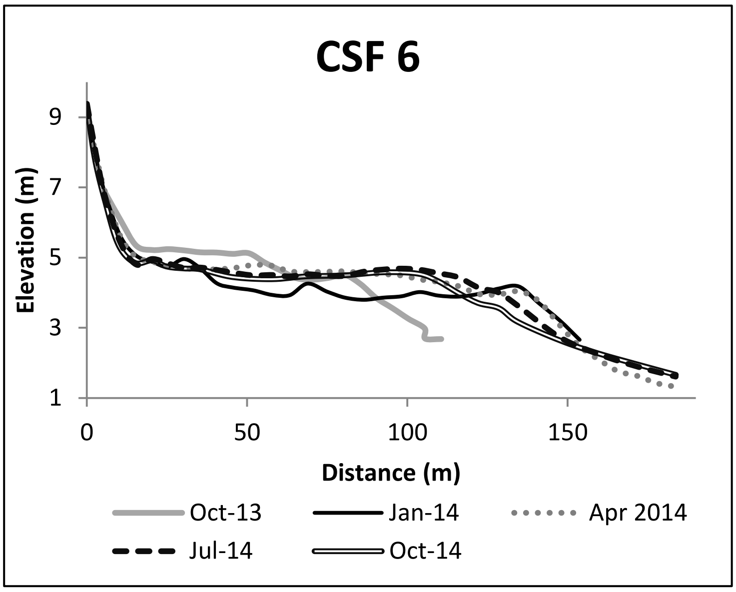

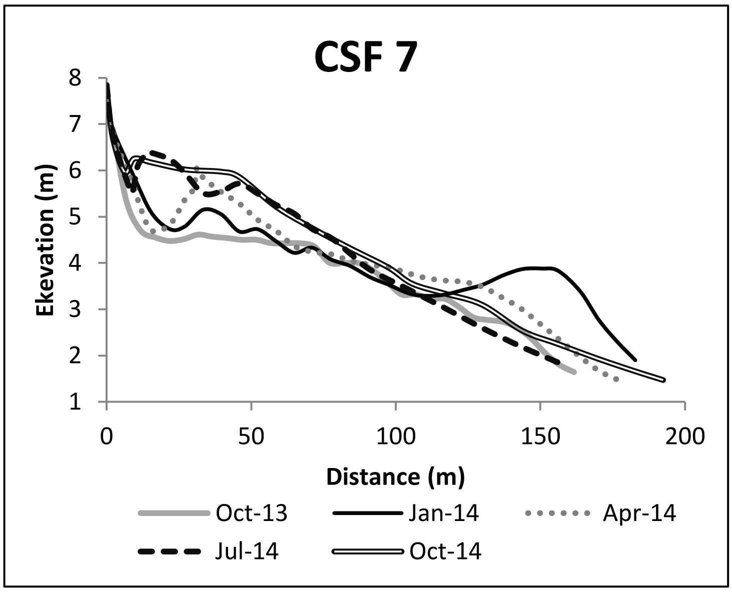

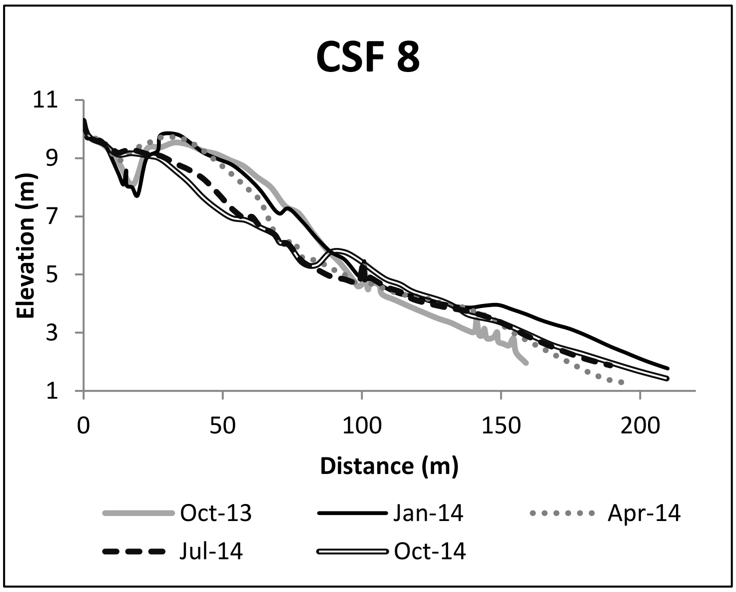

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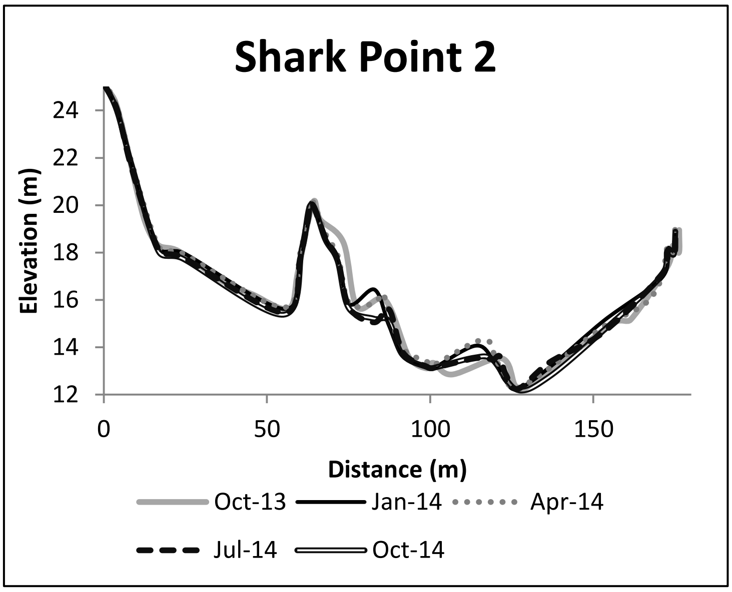
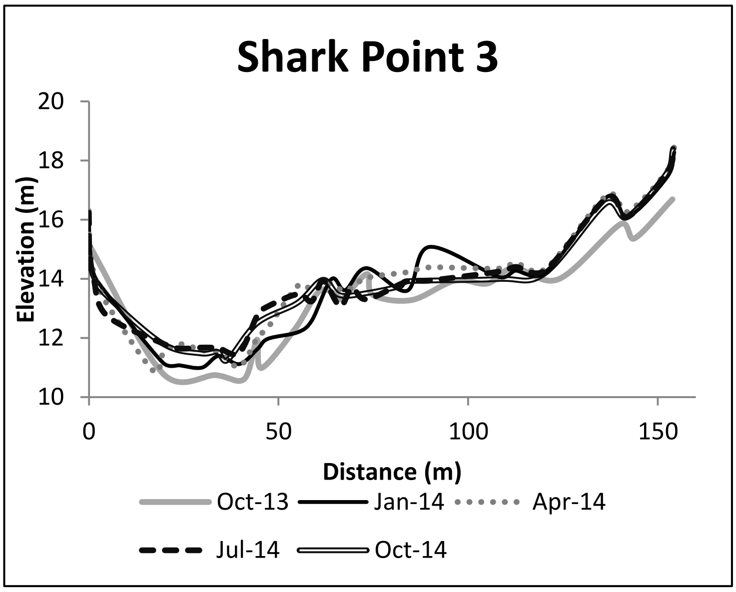
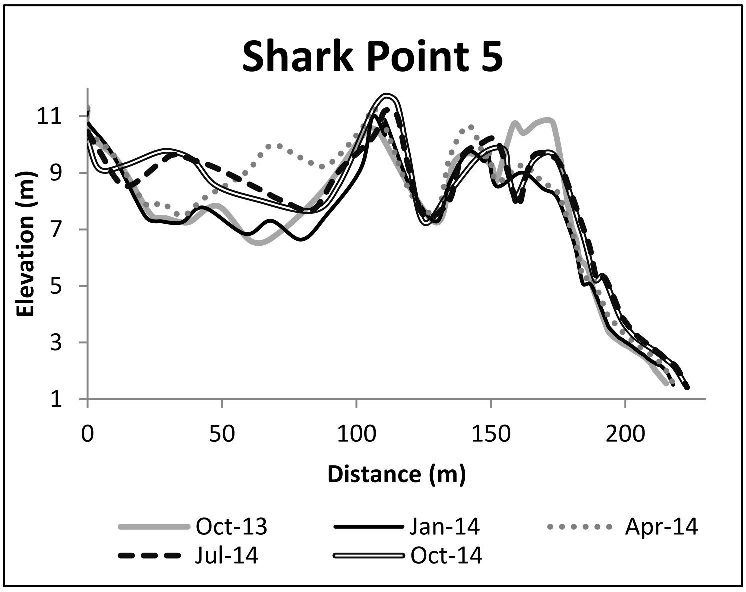
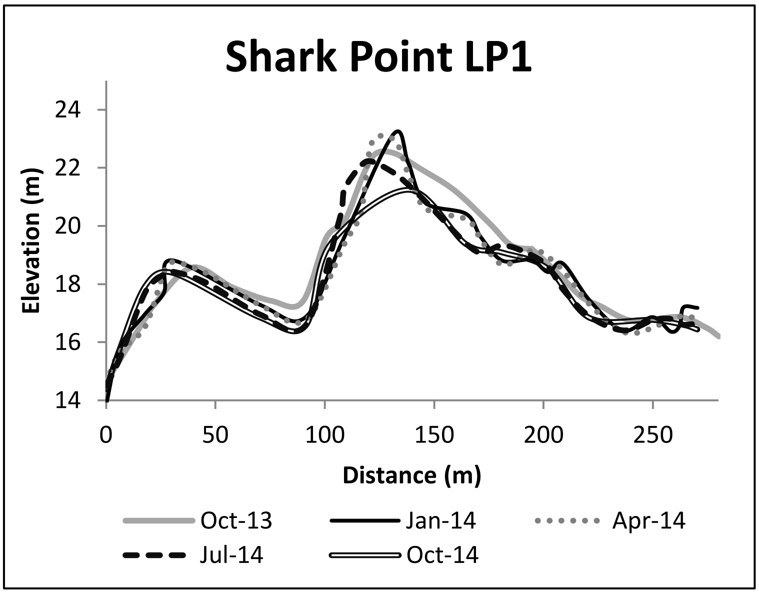
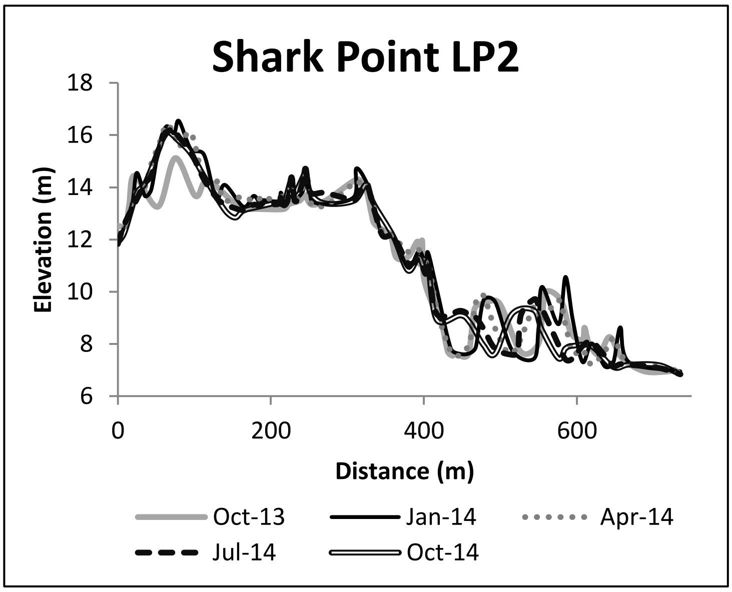


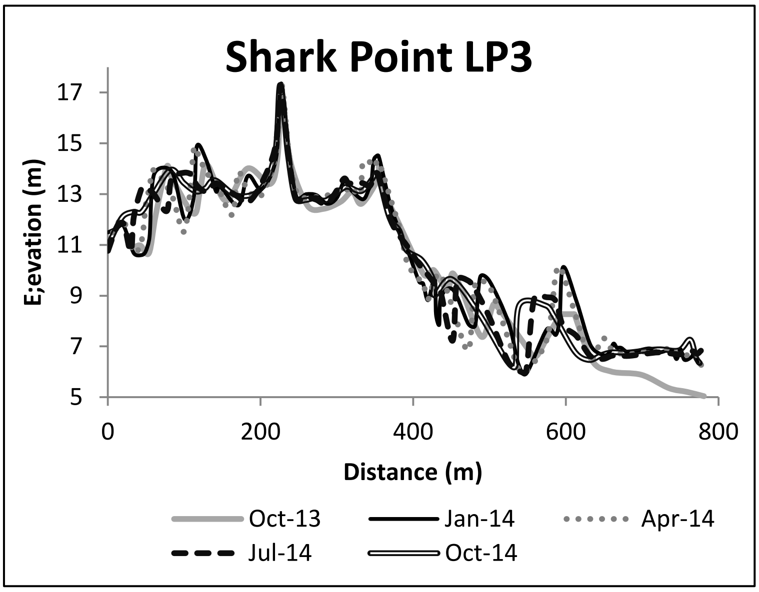


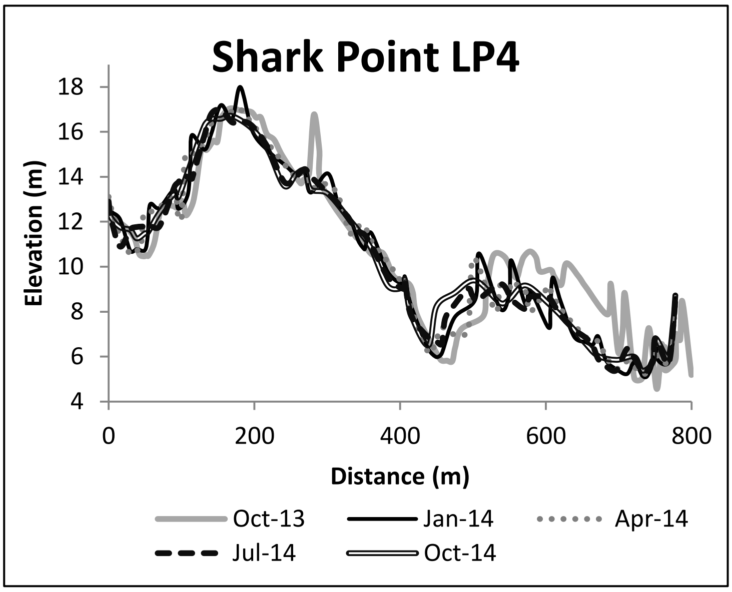


4. Dune surveys (longitudinal profile)









5. Particle size distribution

Table 9: Particle size distribution and low frequency magnetic susceptibility reading of samples

Sample Area	Particle Size (%)							Magnetic (LfR)
	<2000 μm (granules)	<1000 μm (very coarse sand)	<500 μm (coarse sand)	<250 μm (medium sand)	<125 μm (fine sand)	<63 μm (very fine sand)	>63 μm (silt and clay)	
Oyster Bay	0,00	0,00	0.26	64.66	34.84	0.02	0.21	-0.07
Oyster Bay Headland Bypass Dunefield	0.00	0.00	0.55	86.58	12.73	0.11	0.02	0.20
Sand River	0.09	0.02	0.42	79.71	19.51	0.24	0.01	-0.15
Spit	0.19	0.05	0.68	55.11	43.31	0.64	0.02	0.05
St Francis Bay	0.48	0.63	4.75	55.38	37.47	1.26	0.02	0.27
Shark Point	0.00	0.04	0.45	74.04	25.36	0.10	0.02	0.3
Cape St Francis	0.25	0.33	2.27	58.82	38.25	0.08	0.01	0.29
Total Particle Size	0.22	0.27	2.11	63.52	33.38	0.46	0.03	0.13

Note: Particle size descriptions from Bird (2000: 96)