MAINTENANCE MANAGEMENT PLAN FOR THE HEUNINGNES ESTUARY MOUTH UNDER SPECIFIC CONDITIONS

COMPILER: PIERRE DE VILLIERS

SENIOR MANAGER: MARINE AND COASTS OPERATIONS

Heuningnes Estuary, De Mond Nature Reserve

STATEMENT OF THE PROBLEM

The mean annual runoff (MAR) into the Heuningnes Estuary is estimated as 32.39 million m^3, but this has been reduced to 27.35 million m^3 mostly through alien infestation in the catchment area (Anchor Environmental Consultants 2018). The reduced flows to the system means that natural breaching levels (and related breaching opportunities) are reduced. While little information is available on the mouth dynamics of the Heuningnes under the Reference condition, simulated river inflow data, the estuary bathymetry and present mouth behaviour, all paint a picture of intermitted closures occurring decades apart. Due to the flat topography of the area, inundation would have resulted in a very large open water area that would have taken anything from 2 to 10 years to fill up, given variable inflow, seepage and evaporative losses. When full, this significant body of water would have resulted in extremely high outflow velocities, which in turn would have resulted in a deep basin in the lower reaches and enhanced tidal flows that would have assisted in keeping the mouth open for decades after a breaching. In addition, the mouth position would have shifted depending on the lowest lying point in the frontal dune system, adding additional variability to this complex interaction between river flow, tidal exchange and sediment processes.

Under its current state, the mouth of the Heuningnes Estuary has been artificially manipulated since the early 1940s. This was initially undertaken by the then Department of Forestry and more recently by CapeNature. The rationale behind the practise of keeping the mouth permanently open was to prevent backflooding of riparian properties. The concern was that flooding would result in damage to structures and loss of land under crops due to a combination of prolonged inundation and elevated salinity levels due to accumulation of salt in the soil. A maximum flood level of 2 m MSL has been put forward as the limit by landowners (SMEC 2017), however, judging by photographic evidence (Anchor Environmental Consultants 2018), hard infrastructure is still about a metre above this level.

Historic practises of artificially stabilizing dunes on either side of the mouth and erecting barriers to trap longshore wind-blown sand was stopped in 2012 pending further studies. The mouth has remained open since then without manipulation, although sediment build-up in the lower reaches is extensive and closure during low flow periods an eminent prospect.

The Heuningnes estuary is ranked 24th most important in South Africa in terms of its botanical, fish and bird biodiversity (Turpie *et al*. 2010). It has been identified as an important bird area (Barnes 1996) and a desired protected area in two national conservation planning assessments (Turpie & Clark 2007, Turpie et al. 2010). The Heuningnes estuary is also located in the De Mond Nature Reserve and is managed as a bait reserve (no bait collecting allowed). The Heuningnes Estuary is also listed on the Ramsar List of Wetlands of International Importance owing to the presence of key waterfowl that are dependent on the site as habitat, these being the Damara tern (*Sterna balaenarum*) and Caspian tern (*Hydroprogne caspia*). Continued artificial breaching of the estuary at low berm levels is likely to exacerbate sediment build-up in

the lower reaches and will ultimately lead to increased frequency of mouth closure, increased freshening of the system or alternatively development of hypersalinity within the system. All of these outcomes are considered highly undesirable from a conservation perspective, will reduce the biodiversity importance of the system and also the importance of the estuary as a nursery area for commercial fish species. An appropriate compromise needs to between the natural breaching level of 3.0-3.5 m amsl and the historic breaching level of 2.0 m amsl requested by riparian landowners.

OVERALL OBJECTIVE OF THE LOCAL MOUTH MANAGEMENT PROGRAMME

Manage the estuary mouth as an integral part of the Heuningnes Estuary Management Plan that will maintain the healthy ecological conditions of the estuary.

For the Heuningnes Estuary this means that its health assessment rating should be consistent with a B Ecological Category defined as "Largely natural with few modifications" as defined in terms of Department of Water and Sanitation's (DWS) A to F rating system. (Turpie & Clark 2007; Van Niekerk & Turpie 2012).

DESCRIPTION OF THE HEUNINGNES ESTUARY

Table 1. Description of the estuary and its importance.

Threat	Discussion
Location	The Heuningnes Estuary is a relatively large estuary (97.9 km^2) on the southern Cape Coast, approximately 10 km East of Cape Agulhas. The catchment area is approximately 1 793 km^2 in extent and comprises of four subcatchments: Droë, Kars & Poort and Nuwejaars Rivers. The catchment of the Heuningnes River is characterised by hilly slopes in the upper reaches of the catchment and a very flat coastal plain in the lower reaches. Mean Annual Precipitation (MAP) ranges between 431 (at the coast) and 531 (inland) mm per annum. **Downstream boundary:** Estuary mouth 34º42'53.24"; 20º07'09.29"S **Upstream boundary:** Limit of tidal effect (34°42'33.04" S; 19°56'09.03"E) **Lateral boundaries:** Estuary Functional Zone 5 m contour above Mean Sea Level (MSL) along each bank

Threat	Discussion
	

Estuary Importance	The Heuningnes Estuary is a relatively large estuary (97.9 km^2) compared with other South Africa systems. The estuary is ranked 24th most important in South Africa in terms of its botanical, fish and bird biodiversity (Turpie *et al*. 2010). The estuary is rated as "Highly important" based on its Estuary Importance Score (EIS) with a score of 93 out of 100. The EIS takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account.
Conservation status	The Heuningnes estuary is located in the De Mond Nature Reserve and is managed as a bait reserve (no bait collecting allowed) and was included in the subset of estuaries identified as requiring protection in order to conserve South Africa estuarine biodiversity estate (Turpie 2004, Turpie & Clark 2007, Turpie et al. 2012). The Heuningnes Estuary is also listed on the Ramsar List of Wetlands of International Importance owing to the presence of key waterfowl that are dependent on the site as habitat, these being the Damara tern (Sterna balaenarum) and Caspian tern (Hydroprogne caspia).

Important vegetation	The dominant macrophyte habitats in the Heuningnes Estuary include seagrass and salt marsh. Reeds and sedges also occur but are abundant only in Soetendalsvlei. Large areas of salt marsh (Limonium, Salicornia and Sarcocornia spp.) occur in the lower and middle reaches of the Heuningnes Estuary, while stands of reeds and sedges (*Phragmites australis* and *Schoenoplectus scirpoides*) line the water channel in the upper reaches. The salt marshes near the mouth are cut off by levees and are only inundated during extreme high tides. Prior to the artificial management of the mouth, the lower estuary dammed up behind the barrier dune creating a lateral lagoon (Bickerton 1984). Supratidal salt marsh consists of *Sarcocornia pillansii* and *Chrysanthemoides incana*. Fringing reeds in the upper reaches of the estuary likely play an important role in nutrient uptake from agricultural inputs. Heydorn and Grindley (1984) reported the submerged macrophyte Ruppia 3 km from the mouth of the Heuningnes Estuary. It has subsequently been replaced by the seagrass *Zostera capensis*; a clear indication of the increase in saline, tidal conditions. The site visit in February 2017 indicted an expansion of the *Zostera capensis* beds in the lower reaches. There were also heavily epiphytized which indicates calm still water conditions. These seagrass beds will increase in cover when the mouth is restricted and flow velocities are reduced. However, the next large flood will likely remove these beds. Historically Heuningnes River and Estuary were connected to Soetendalsvlei. The latter now consists of a large reed bed of *Phragmites australis* and *Schoenoplectus scirpoides* that separates the vlei into a northern and southern section. Reed growth is restricted to the western shore due to high winds that blow throughout the year in the region (Gordon 2012). Kotsedi (2007) recorded 45 plant species at Soetendalsvlei mostly from the family Poaceae and Cyperaceae. The submerged macrophyte *Potamogeton pectinatus* (pondweed) was present in 2007. Supratidal salt marsh of *Sarcocornia pillansii* and *Bassia diffusia* surrounds the wetland and is inundated under high rainfall events.
Important fish nursery	In total, 72 species of fish from 34 families have been recorded from the Heuningnes Estuary, Zoetendalsvlei and surf-zone adjacent to the mouth. Resident fish that breed only in estuaries (Category Ia) comprise four species - estuarine round herring *Gilchristella aestuaria*, Cape halfbeak *Hyporamphus capensis*, kappie blenny *Omobranchus woodii* and the yet to be confirmed but unlikely Knysna seahorse *Hippocampus capensis*. Fish that breed in the marine and estuarine environments (Category Ib) e.g. estuarine pipefish *Syngnathus temminckii* and prison goby *Caffrogobius gilchristi* were represented by seven species. Obligate estuary-dependent fish that have to spend at least the first year of life in estuaries (IIa) e.g. dusky kob *Argyrosomus japonicus* and white steenbras *Lithognathus lithognathus*, contributed 10 species whereas partially estuary-dependent (IIb) e.g. blackhand sole *Solea turbynei* and marine opportunists that use the best of both worlds (IIc) e.g. harder *Liza richardsonii* provided six and seven species, respectively. Marine vagrants (III) e.g. lesser guitarfish *Acroteriobatus annulatus* reflected the predominantly open estuary mouth with a relatively high 26 species. Freshwater fish (IV) comprised eight species but only three

were indigenous e.g. *Galaxias zebratus*, the rest introduced or translocated e.g. bass *Micropterus* spp. Three catadromous eels *Anguillidae* (V) have also been recorded from the Heuningnes catchment and recruit via the estuary.

Altogether, including Ia estuarine residents, obligate-dependents and catadromous fish, 17 (24%) of the Heuningnes fish assemblage are completely dependent on estuaries to complete their life-cycle, 20 (28%) are partially estuary-dependent and the remainder split between estuary-independent marine (36%) and freshwater (11%) species. The proportion of estuary-associated fish in the Heuningnes Estuary fish assemblage is relatively low compared to the Breede, Gouritz and other south-coast estuaries but is an artefact of the high contribution of marine vagrants there. Absolute values of estuary-associated fish either match or exceed all adjacent and nearby systems on the south-coast.

Of the Heuningnes estuary fish assemblage, 10 (14%) e.g. *Hyporamphus capensis* and 21 (33%) e.g. *L. lithognathus* are South African and southern African endemics respectively. Five (7%) e.g. *Cyprinus carpio* are introduced alien or translocated species. The remaining 34 (47%) e.g. *Lichia amia*, are cosmopolitan. The high degree of endemism is typical of Cape south coast systems.

In the Heuningnes Estuary, high water levels inundate marginal areas and re-establish connectivity between the estuary, Zoetendalsvlei and tributaries, allowing juveniles of fish such as moony M. falciformis and freshwater mullet *Myxus capensis* to recruit upstream, and for landlocked adults to find their way back to the sea. Size distributions and age-length keys of these fish suggest that many of these fish remain in Zoetendalsvlei for 8-10 years and that both recruitment and emigration are linked with 1:10 year flood events. These event-years are often associated with a second late-summer/autumn (as opposed to spring/early summer) spawning peak of *L. richardsonii* in the sea, assumedly due to the emigrants becoming reproductively active once they've left the estuary.

Recruitment and emigration of catadromous eels *Anguilla* spp. are also strongly linked to flow. Juvenile glass eels recruit into natal estuaries and catchments following olfactory cues which they can detect at dilutions >109 in the sea. Most recruitment takes place over dark-moon spring tides, probably predator avoidance behaviour. They quickly metamorphose into elvers but can retard their own growth, making it easier to move over obstacles on their way upstream. Depending on species, adult eels can spend 8-30 years in freshwater before returning to the sea. Return migration is cued by the first winter spates, whereupon adults move downstream gradually transforming into silver eels, their eyes growing bigger and gut atrophying. Once in the sea, they travel at depth to their abyssal spawning grounds which for southern African (and West Indian Ocean) eels seems to be east of Madagascar, where they spawn and die. All of the Anguillidae

	are very susceptible to poor water quality including that which inhibits olfactory location of natal streams. The Heuningnes spotted grunter *Pomadasys commersonii* population is one of the first to become established in the southern Cape and are the same fish caught in the occasional "grunter runs" in Struisbaai Harbour so spread throughout 10 km of the bay. Data on movements of the Heuningnes *P. commersonii* are limited. Of 45 tagged in the Heuningnes estuary under the ORI Tagging Programme in the 20 years up to 2015, none were recaptured. Dusky kob *A. japonicus* were slightly better, with 34 tagged, four recaptured, two in the Heuningnes and two elsewhere at unknown localities. One *A. japonicus* tagged at Koppie Alleen in the De Hoop MPA was recaptured in the Heuningnes estuary 79 days later, verifying links between the estuary and MPA. The one Zambezi shark *Carcharhinus leucas* reported from the system is most likely of the same nomadic population moving between the southern Cape, offshore seamounts and Mozambique.
Important Bird site	The Heuningnes River and estuary system is a complex wetland system consisting of the Nuwejaarsrivier and associated marshes, Soetendalsvlei, and the Heuningnes River and its estuary, which is located in the De Mond Nature Reserve (Bird Life South Africa 2015). The estuary is ranked as one of the top 42 estuaries in South Africa in terms of its importance for birds (Turpie 1995). There are 16 Red Data List bird species known to occur in and around the estuary. The system is recognised as an Important Bird and Biodiversity Area (IBA) with the wetlands, protected areas and agricultural lands, providing excellent habitat for a wide diversity of birds (Bird Life South Africa 2015). The estuary, including the dunes on either side, was designated as a Ramsar Site (Wetlands of International Importance) in 1986. The IBA represents a stronghold for the Blue Crane, which has been recorded at Soetendalsvlei. The De Mond Nature Reserve is an important breeding site for Caspian and Damara Terns, Kittlitz's Plover and 300 pairs of Kelp Gull. African Black Oystercatchers are known to breed in the reserve too and the threatened Cape Cormorant roosts along the coast and at the estuary mouth. Lesser and Greater Flamingo as well as Great White Pelican visit both the estuary and Soetendalsvlei. Avifauna counts were carried out by Underhill & Cooper (1983) during the summer of 1977, 1979 and 1981 on the lower estuary, one winter count was carried out in July 1979 on the lower estuary, one summer count on the upper estuary in 1979, and one summer count on Soetendalsvlei in 1981. Over this period, 53 waterbird species were recorded on the Heuningnes estuary and Soetendalsvlei. During the summer counts on the estuary, an average of 857 waterbirds were counted from 19 species. During the winter count in 1979 only 43 waterbirds were recorded from 9 species. This difference is largely due to the use of the estuary by migratory waders in the summer months. Hundreds of Curlew Sandpiper, Little Stint and Sanderling were recorded during the summer counts. During the summer count in 1981, 1000 unidentified terns were also recorded. During the summer count of 1981 on Soetendalsvlei, a total of 38 waterbird species comprising a total of 7160 birds were counted. Large groups of waterfowl and waders

	were recorded during this count. Thousands of Egyptian Geese, Redknobbed Coot, Curlew Sandpiper and Ruff were recorded and hundreds of Spurwinged Goose, South African Shelduck, Yellow-billed Duck, Little Stint and Kittlitz's Plover were also counted. Coordinated Waterbird Counts (CWAC) are available for the period July 1993 – July 2016 for the estuary and for the period 2013-2016 for Soetendalsvlei. For most years, a single summer and winter count were conducted, except for 2005 and the period 2010-2012 when no counts were recorded. The last summer CWAC count was conducted in January 2013. In February 2017, a count was conducted on the lower (from the estuary mouth to the footbridge) and upper (from the footbridge to approximately 10 km upstream where the R319 road crosses the Heuningnes River) reaches of the estuary. A total of 83 waterbird species have been recorded on the Heuningnes Estuary and Soetendalsvlei since 1993 with 65 species recorded on the estuary and 63 species recorded on the vlei. A number of wader species have been counted at the estuary but not seen at the vlei. Similarly, a number of waterfowl species have been recorded on the vlei but not on the estuary. Of the 65 species recorded on the estuary, 31 are estuary associated species. The more common visitors include the Common Ringed Plover, White-fronted Plover, Kittlitz's Plover, Kelp Gull, Caspian Tern, African Black Oystercatcher and Grey Plover. Scarcer, more localised species include Bar-tailed Godwit, Curlew, Terek Sandpiper, and Greater Sand Plover. A number of tern species feed at the estuary mouth and roost on the sandbanks. These include Caspian, Swift, Common, and Sandwich Terns. Small numbers of the Damara Tern occasionally roost at the estuary or feed over the estuary mouth. A small colony of 11-13 breeding pairs of Damara Terns breed on the secluded dunes within the De Mond Nature Reserve between November and February, representing 8-17% of South Africa's population (Hoekstra & Waller 2014.). The reserve also protects an important breeding colony of Caspian Terns. Over the years a few vagrants have been recorded at the estuary, including American Golden Plover, Dunlin and Temminck's Stint. Waterfowl dominate the avifauna on Soetendalsvlei with the most frequently seen species including Egyptian Goose, Spurwinged Goose, Red-knobbed Coot and Yellowbilled Duck. Other frequently seen species include African Darter, Reed Cormorant, African Spoonbill and Grey Heron. African Fish-Eagle were recorded during all of the CWAC counts conducted on the vlei since 2013. From 1993-2016, the average number of waterbirds recorded on the estuary in summer was 1473 compared to 240 for winter. The number of species recorded for this period was slightly higher in summer than in winter with an average of 21 and 18 species recorded, respectively). The highest waterbird count was in January 2013 when a total of 6540 birds were recorded, including 6000 Swift Terns. In February 2001 and 2004, thousands of Common and Sandwich Terns were also counted. The most recent summer count, conducted in February 2017, included 1879 waterbirds from 34 species, higher than the overall average for numbers and species recorded since 1993. This higher count is most likely the result of different counting techniques; with the regular CWAC counts

	being conducted on foot within the boundaries of the nature reserve and the recent count being done by boat extending to areas outside of the reserve. From 2013-2016 the average number of waterbirds recorded on the vlei in summer was 268 compared to 170 for winter and the average number of species was 12 in summer and 13 in winter. This is significantly lower than the count conducted by Underhill & Cooper in 1981. The highest waterbird count was in February 2013 when 702 waterbirds were recorded.
Estuary Condition w.r.t breaching	The Heuningnes Estuary rated as ***Moderately modified*** (Category C in DWS rating system). This arises from significant changes in water quality, physical habitats, and macrophytes (vegetation). In the RDM study conducted for the system (Anchor Environmental Consultants 2018), it was identified that non-flow impacts have played a major role in the degradation of the estuary, but that flow-related impacts are still an important cause of its degradation. The highest priority for rehabilitation was identified as restoring the quantity and quality of influent water. Of the non-flow-related impacts, mouth stabilisation and artificial breaching, elevated nutrient inputs from the catchment and transformation of natural vegetation on the estuary floodplain (mostly supratidal saltmarsh) to agricultural crops (wheat barley) and grazing land were found to be the most important factors that influenced the health of the system. In recent years, the mouth has been breached as per the long-standing arrangement with the riparian owners. A maximum flood level of 2 m MSL has been put forward by landowners, the level above which they contend would flood cultivated and grazing lands leading to crop and livestock losses. However, in the RDM study (Anchor Environmental Consultants 2018) it was determined that hard infrastructure is still about a metre above this level. It was also pointed out in this study that a high spring tide is > 2 m MSL. During the emergency breaching process that took place in September 2020 the mouth was artificially breached at 2.6m with the support of all stakeholders and role players. This would be the most appropriate level to incorporate into the MMP. Breaching at these low levels has resulted in significant sedimentation in the estuary (due to reduced scouring during breaching) and also a loss of connectivity with Soetendalsvlei which, historically, was integrally connected with the estuary.
Recommended Ecological Condition	The impacts on the Heuningnes Estuary can be mitigated with very little effort. The recommended health status is a ***Category A (*Unmodified, natural**) or Best Attainable State (BAS) because the system is a conservation priority, an important fish nursery, important bird area, as well as the ease with which restoration can be achieved. The BAS for the Heuningnes estuary based on fairly modest (and easily achievable) flow restoration is a C (same as Present but 3% higher). A further modest increase in the health score can be achieved by increasing the breaching threshold from 2.0 m amsl (the current practice) to at least 2.5 m amsl (healthy score increases from 69 to 70% but remains in a "C" category).

	Increasing the health state to the required B or even an A category requires restoration of flow and increasing the breaching threshold, as well as addressing some of the other non-flow related issues affecting the estuary. These additional restoration measures can be implemented relatively easily, and it was thus strongly recommended in the RDM study that this is done as soon as possible and that the ecological flow requirements for the estuary be set for a B category.

MOTIVATION FOR ARTIFICIAL BREACHING

The Present Ecological State (PES) for the Heuningnes is a C while the Recommended Ecological Category (REC) is an A or Best Attainable State (BAS). Restoration of freshwater inflow (which can largely be accomplished to a large extent by removal of alien invasive vegetation from the catchment) will improve the health of the estuary only marginally (by 3%) but will not increase the health category beyond this. Restoring this system to a B or A category (which is entirely achievable) will also require reclamation of a significant portion of the historic floodplain area of the estuary (currently under agriculture or use as grazing land, this land may need to be bought up by CapeNature or SANParks), reducing nutrient inputs (mostly die to application of agricultural fertilizers but also the Bredasdorp WWTW), eliminating illegal fishing on the system, minimising interference with natural mouth dynamics (increase breaching height to at least 2.5 m amsl), limiting numbers of visitors to the estuary (will limit disturbance to birds and fishing pressure), and removal of the remnants of the causeway below Soetendalsvlei. Given the high importance of this system, it is strongly recommended that these remedial actions be implemented.

While little information is available on the mouth dynamics of the Heuningnes under the Reference condition, simulated river inflow data, the estuary bathymetry and present mouth behaviour, all paint a picture of intermitted closures occurring decades apart. However, as a result of the flat topography of the area, inundation would have resulted in a very large open water area that would have taken anything from 2 to 10 years to fill up, given variable inflow, seepage and evaporative losses. When full, this significant body of water would have resulted in extremely high outflow velocities, which in turn would have resulted in a deep basin in the lower reaches and enhanced tidal flows that would have assisted in keeping the mouth open for decades after a breaching. In addition, the mouth position would have shifted depending on the lowest lying point in the frontal dune system, adding additional variability to this complex interaction between river flow, tidal exchange and sediment processes.

Under its current state, the mouth of the Heuningnes Estuary has been artificially manipulated since the early 1940s. This was initially undertaken by the then Department of Forestry and more recently by CapeNature. The rationale behind the practise of keeping the mouth permanently open was to prevent backflooding of riparian properties. The concern was that flooding would result in damage to structures and loss of land under crops due to a combination of prolonged inundation and elevated salinity levels due to accumulation of salt in the soil.

The mouth has closed on only a few occasions since the 1940s. On one occasion, it was closed for a three-year period between 1973 and 1976 but was eventually manually breached when the system started to fill after good rains. There also seems to have been an attempt to breach the system in 1974. The last time the mouth closed was in August 2007, but it was again manually breached on 24 September 2007 after rains threatened to flood the riparian areas. From the 2007 water level record, it is clear that the system started closing earlier in the year as indicated by the low tide levels of February 2007 that shows very constricted levels for about a week.

The practise of actively stabilizing dunes on either side of the mouth and erecting barriers to trap longshore wind-blown sand was stopped in 2012 pending further studies. The mouth has remained open since then without manipulation, although sediment build-up in the lower reaches is extensive and closure during low flow periods an eminent prospect.

In recent years, the mouth has been breached as per the long-standing arrangement with the riparian owners. A maximum flood level of 2 m MSL has been put forward by landowners, the level above which they contend would flood cultivated and grazing lands leading to crop and livestock losses. However, in the RDM study (Anchor Environmental Consultants 2018) it was determined that hard infrastructure is still about a metre above this level. It was also pointed out in this study that a high spring tide is > 2 m MSL.

Breaching at these low levels has resulted in significant sedimentation in the estuary (due to reduced scouring during breaching) and also a loss of connectivity with Soetendalsvlei which, historically, was integrally connected with the estuary.

While the RDM study only considered breaching scenarios with berm heights at 2.0 and 3.0 m amsl, it was recognised that the incremental benefits of increasing the breaching threshold from 2.5 to 3.0 m may not be justified, and may even be outweighed by loss of agricultural land on the floodplain. Numerical modelling studies undertaken by SMEC (2017) suggests that the extent of the scouring in the estuary increases significantly when the breaching threshold is increased from 2.0 to 2.5 m (increases from 2.2 to 3.0 km upstream) but does not change much above this level (scouring extent does not change at all when the breaching threshold is increased from 2.5 to 3.0 m amsl). By contrast, expansion in the area inundated under a 1: 50 year flood increase by a relatively modest 147.0 if one increases the breaching threshold from 2.0 to 2.5 ha, but increases by a further 540.1 ha when increasing the breaching threshold from 2.5 to 3.0 mamsl. A similar outcome is evident under a 1: 100 year flood, with the inundated area increasing by 149.2 ha when the breaching threshold is raised from 2.0 to 2.5 amsl, but increases by a further 390.6 ha when increasing the breaching threshold from 2.5 to 3.0 m amsl.

A summary of the motivations for potential artificial breaching is provided below in Table 2.

ASSESSMENT OF RISKS, THREATS, OPPORTUNITIES ASSOCIATED WITH MOUTH MANAGEMENT DECISIONS

Table 2: Summary of artificial breaching motivation

	Potential Threat	Relevance	
Human wellbeing and safety	Threat to human life (as a result of high water levels)	No threats to human life	
	Threat to immoveable property and infrastructure (as a result of high water levels)	Yes, there are a number of low lying properties around the Heuningnes Estuary including the De Mond Nature Reserve, riverfront cottages and agricultural fields.	
	Human health impact (e.g. flooding of sewage pump station, septic tanks, chemical storage yards, etc.)	Water Quality in the Heuningnes Estuary can deteriorate to where it poses a risk to human health.	
	Potential loss of agricultural resources (as a result of high water levels)	There has been significant transformation of the supratidal and floodplain habitat in the EFZ of the Heuningnes estuary as a result of agricultural development, drainage canals, causeways/weirs and road crossings. Approximately 80% of the total vegetated area in the estuary functional zone consists of agriculture and disturbed floodplain (3214.32 ha of 3999.48 ha).	
	Potential impact on nearshore environment if breached (e.g. aquaculture facilities)	Not applicable.	
	Loss/impaired access (e.g. roads, footpaths, cattle crossings)	Access to the De Mond Nature reserve and other riparian properties may be restricted if the mouth remains closed for a long period of time and water levels are allowed to build up to very high levels.	
	Harmful / Noxious algal blooms	Not applicable.	
	Impact(s) on recreational use (e.g. increase depth / surface area when mouth is closed, reduce fishing).	Recreational activities such as fishing and bird watching in the Heuningnes Estuary can be affected by mouth state.	
		Impact of artificial breaching	Recreational fishing: Enhanced by open mouth conditions. Birdwatching: More estuarine associated species such as waders present in the intertidal areas during the open mouth state, but large number of water fowl are disturbed by breaching
		Impact of NOT breaching	Recreational fish catches will be reduced (number and size of fish) if the mouth has been closed for an extended period and/or if the mouth is breached too frequently or at levels that are too low. Birdwatching: Waterfowl increase significantly during closed mouth state.
Ecosystem requirements	Impact on avifauna abundance, species richness/ community composition	Important bird habitat	The Heuningnes estuary has been recognised as one of South Africa's Important Bird Areas (CSIR 2011).
		Impact of artificial breaching	Breaching at low berm levels has resulted in significant sedimentation in the estuary (due to reduced scouring during breaching) and also a loss of connectivity with Soetendalsvlei which, historically, was integrally connected with the estuary The open state, following mouth breaching provides exposed Intertidally areas which favours Waders, gulls and terns (e.g. Curlew Sandpiper, Kittlitz Plover, Common Tern and Hartlaub's Gull) Post breaching, open state conditions also favour Flamingos, wading birds (e.g. Greater Flamingo, Black-winged Stilt, Sacred Ibis, Grey Heron and Egrets.

Potential Threat		Relevance	
			Breaching has a negative effect on water fowl.
		Impact of NOT breaching	The deep water and abundant macrophytes associated with not breaching favours Waterfowl and piscivores (e.g. Red-knobbed Coot, Great Crested Grebe, Southern Pochard, Yellow-billed Duck, Red-billed Teal and Reed Cormorant) Mouth closures and related high water levels have negative effect on Waders, gulls and terns as they prefer exposed sandbanks in lower estuary. The higher water levels and reduction in fish abundance during closed mouth state also indirectly impact on the Cormorants, wading piscivores, kingfishers and fish-eagles.
		Occurrence of avian botulism	Not a major concern in this system.
	Impact on estuarine fish abundance, species richness/ community composition	Important fish nursery	Artificial breaching may be necessary in order to maintain the ecological functioning of the estuary and its value as a nursery area for fish; this being achieved by ensuring that the mouth is open to allow recruitment and emigration during the peak recruitment period during spring – early summer (August – November).
		Impact of artificial breaching	Positive impacts are recruitment of larval and juvenile fish and return of adolescents and reproductively active fish to the sea to spawn. Negative aspects are a temporary reduction in water volume and littoral habitat and limited mortality of resident benthic species through stranding in algal and macrophyte beds. Breaching at low berm levels has resulted in significant sedimentation in the estuary (due to reduced scouring during breaching) and also a loss of connectivity with Soetendalsvlei which, historically, was integrally connected with the estuary
		Impact of NOT breaching	Significant nursery area (>10%) not available to juvenile fish on the Cape south coast and eventual drop in recruitment or available biomass of exploited species to marine fisheries.
		Occurrence of fish kills	Yes, associate with low salinities (< 6 psu). Fish kills arising from hypo / hypersalinity and / or estuarine HABs (e.g. *Microcystis*, golden algae *Prymnesium parvum*) may be mitigated by open mouth conditions. Fish may also escape hypoxia, ammonia toxicity etc. arising from poor water quality in the estuary. Seawater at 35 psu will also treat pathogens such as the water mould Epizootic Ulcerative Syndrome (EUS) now prevalent in many estuaries and catchments. The above said, ill-timed or inadequate breaching at low water levels and with little water movement may compromise already-stressed fishes' immunity to pathogens and exacerbate fatalities.
	Impact on estuarine invertebrate abundance, species richness/ community composition	Impact of artificial breaching	Breaching at low berm levels has resulted in significant sedimentation in the estuary (due to reduced scouring during breaching) and also a loss of connectivity with Soetendalsvlei which, historically, was integrally connected with the estuary

Potential Threat		Relevance	
			During open mouth salinity levels increase. When salinities increase above 10 psu it creates opportunity for euryhaline species) to increase in biomass and abundance An open mouth is also important larval recruitment from the marine environment and vice versa.
		Impact of NOT breaching	Prolonged closed mouth conditions lead to decrease in species richness (absence of marine associated species). The associated decrease in salinity has a negative impact on invertebrates within the lower reaches of the Heuningnes Estuary which are adapted to life in a more saline tidal system.
		Occurrence of invertebrate kills	No information available on the Heuningnes Estuary but invertebrate mortalities have occurred in the Breede (sandprawn *Callichirus krausi*)ammonia toxicity and hypoxia impact benthic invertebrates and the osmotic stress arising from abrupt changes in salinity may help control pathogens and parasites.
	Estuarine Macrophytes (plants)	Impact of artificial breaching	Open mouth conditions associated with artificial breaching create intertidal habitat for salt marsh and reeds and sedges. Fluctuating water levels would decrease submerged macrophyte biomass and extent. Strong tidal flows could limit the establishment of submerged macrophytes in lower reaches. Submerged macrophyte area cover will vary with seasonal water level. When the mouth breaches, 60 to 80 % of these beds are lost through exposure (CSIR 2011). Salt marsh expands when water level is low and will continue to grow even when inundated, as long as it is not covered for more than 2 to 3 months. Salt marsh expands rapidly into exposed areas when water level drops and 100% cover can be achieved within 1 to 2 months. Increased sediment salinity due to evaporation may result in a temporal loss of species. Dune stabilisation along the coastline adjacent to the Heuningnes estuary has led to a build-up of sand reducing/preventing natural breaching. Increased sedimentation in the lower reaches may also reduce the tidal elevation range, thereby restricting salt marsh zonation.
		Impact of NOT breaching (i.e. die back of saltmarsh)	Submerged macrophytes expand but restricted to shallower areas. The large submerged macrophyte beds that develop during the closed phase are important as they have diverse faunal communities associated with them. 10 % of the *Ruppia* beds are estimated to be eaten by coots and 10 % by fish (associated epiphytic fauna on the leaves of Ruppia). Anthropogenic nutrient inputs presently encourages growth. Die-back occur of salt marsh, reeds and sedges due to inundation and high water level (>1.6 m MSL).
	Water quality Thresholds of concern (that would compromise estuarine ecosystem or ecosystem services	Salinity (high or low) that would compromise ecosystem or ecosystem services	Low salinities (<6 psu) tend to develop within 2 to 3 years after a breaching. Low salinities have been associated with fish kills in other estuaries (e.g. Bot) as they increase the susceptibility of fish to other environmental stress (e.g. hypoxia (low oxygen) or low temperatures)

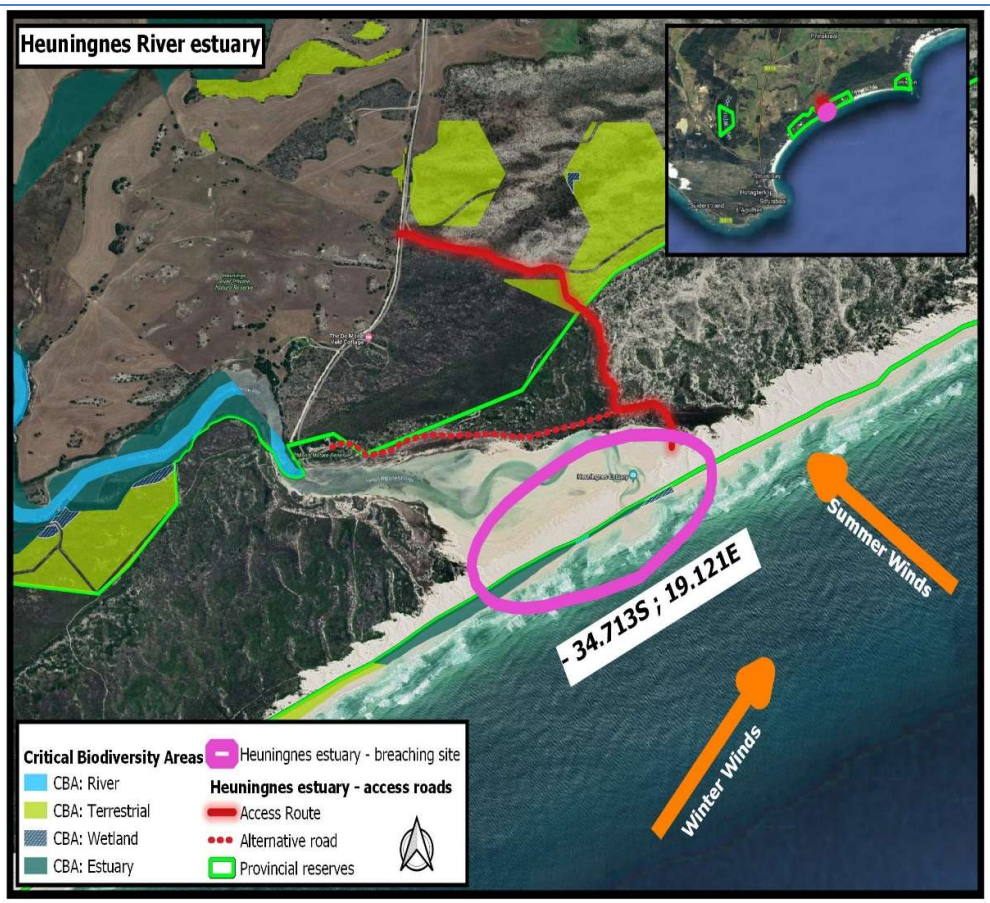
Potential Threat		Relevance	
		Dissolve Oxygen	< 4 mg/l
		Ammonia levels	Not a major concern.
		Toxic substance	Not a major concern.
	Eutrophication	Excessive reed growth	Increased salinity associated with breaching assist with the control excessive reed growth (i.e. cannot survive when exposed to higher salinities)
		Macrophyte blooms	Higher salinities following breaching assist with the control of excessive macrophyte blooms
		Harmful algal blooms	Currently not relevant.
	Sedimentation	On-going sedimentation	Breaching at low water level causes on-going sedimentation
	Type	**Yes/No**	**Motivation**
	Major flood events associated with severe flood damage	Yes	This is only an emergency when water levels in the estuary is high at the time of the flood
	Poor and/or unfavourable water quality	Yes	Low oxygen levels throughout the system may be considered an emergency (e.g. levels consistently below 4 mg/l and/or stressed observed in fish populations but the situation must be verified by a qualified estuarine ecologists before the breaching can be approved) Low salinity levels (especially if low temperature is experienced/predicted at the same time – pre=conditions for major fish kill. Artificial breaching will not be considered to flush polluted water out of the estuary (which will pollute the nearshore).
	Fish kills	Yes	DFFE to determine if major fish kill can be remedied by breaching
	Hazardous spill	Yes	Breaching will only be considered if hazardous substance hold no risk to nearshore environment and the event is registered as an disaster In the event of an Oil spill at sea, the mouth(s) of the Heuningnes Estuary can be closed temporarily to prevent oil from entering the system.

INTEGRATED ASSESSMENT

The following breaching specifications need to be met before artificial breaching of the Heuningnes Estuary can be considered (Table 4):

Table 4: Heuningnes Estuary Breaching Specifications

Breaching considerations	Details		
Minimum breaching level (water level should be as high as possible	>2.5 m msl	Y	Level to MSL
	It is recommended that the CapeNature police the berm when high water levels may tempt local people to artificially breach the estuary.		

before breaching)	
Optimum breaching period (if applicable)	01 May – 31 September
Neap-spring breaching considerations	Preferably 3-4 days before spring tide, but priority should be given to wave conditions and water levels. Higher water levels generate greater outflow so this recommendation can be over ruled to prevent significant seepage and evaporation losses.
Timing of breaching	Breach 2 hrs before high tide, or just after high tide (to prevent high waves from reclosing the opening), to maximize the outflow.
Consider safety of public during breaching	Breaching at the Heuningnes Estuary may pose a risk to public safety, e.g. anglers on the beach, children and dogs falling in outflow channel. Care should therefore be taken with the general public to ensure their safety.
Breaching trench to maximize outflow	Excavated a deep and wide trench with backactor before breaching to maximize outflow.
Location of the breaching position.	Lowest point on the berm opposite the main estuary channel
Propose area of breaching position	
Estimate amount of sediment to be moved during breaching	Not applicable, as amounts vary significantly between breachings. It cannot be determined in advance.
Disposal of sediment	Sediment to be placed a few meters from outflow channel so not to interfere with initial outflow, but close enough that it can be washed away to sea during the breaching event.

removed during excavation	
Water Quality considerations related to breaching	Salinity: < 6 ppt throughout the system for greater than 3 months (must be verified by qualified estuarine ecologist prior to approval of breaching) OR Salinity: > 38 ppt in significant portions of the system
	Oxygen: < 4 mg/l (must be verified by qualified estuarine ecologist prior to approval of breaching)
	Ammonia: Currently not a consideration for breaching in this systems
	Toxic substances: Currently not a consideration for breaching of this system
Ecological considerations	Birds: Breaching to be conducted between 1 May and 31 September where possible to not interfere with optimum breading seasons.
	Fish: Breaching to be conducted between 1 May and 31 September where possible to not maximize potential for recruitment.
	Invertebrates: Not applicable
	Plants: Not applicable.

According to the new Environmental Impact Assessment (EIA) Regulations promulgated on 18 June 2010 in terms of the National Environmental Management Act 1998, the artificial mouth breaching may not commence without an environmental authorisation from the competent authority:

The infilling or depositing of any material of more than 5 cubic metres into, or the dredging, excavation, removal or moving of soil, sand, shells, shell grit, pebbles or rock from:

I. a watercourse;
II. the sea;
III. the seashore;
IV. the littoral active zone, an estuary or a distance of 100 metres inland of the high-water mark of the sea or an estuary, whichever distance is the greater

but excluding where such infilling, depositing, dredging, excavation, removal or moving

I. is for maintenance purposes undertaken in accordance with a management plan agreed to by the relevant environmental authority; or
II. occurs behind the development setback line.

[Listing Notice 1, Activity Number 18]

Application for a special dispensation to implement the mouth management plan for a period of five years (at which time it will be subject to specialist review) is therefore required from DFFE in terms of the need for ecosystem maintenance.

RELEVANT AUTHORITIES

Table 3 lists the Key lead authorities involved in artificial breaching at the Heuningnes Estuary.

Table 3: Key lead authority involved in artificial breaching

Management authority	Cape Nature
Advisory Committee	Heuningnes Estuary Forum (HEF)

Authorisation (breaching / emergency)	DFFE	
Lead authority	**Breaching sub-committee**	**Minimum consultation In case of Emergency**
CapeNature	✓	✓
District Municipality	✓	✓
DEADP	✓	✗
Department of Forestry Fisheries and Environment Affairs	✓	✗
Department of Agriculture	✓	✓
Department of Water and Sanitation	✗	✗
SANParks	✓	✓
NGOs	✓	✗

The decision to artificially breach will be made by a Breaching sub-committee comprising the DeMond Nature Reserve Manager, HEF Chairperson and the CapeNature Landscape South Manager and Marine and Coasts Operations Manager following consultation with at least two members of a team of ecological specialists that include at least one from the DFFE: Inshore Fisheries Research and DFFE: Estuaries Management.

Data on water level, berm height, salinity, as well as water quality parameters where feasible, will be collated by the CapeNature and DWS.

Once the Breaching sub-committee has decided that an artificial breach must occur, CapeNature, shall be responsible for overseeing the breaching activities.

Disaster Management	Authority/Organisation	Status
Early warning system	South African Weather Services (weather)	Yes
	DWS warning system (flow/water levels/dam safety)	No
Disaster Management Plan	CapeNature/Overberg District Municipality	Yes
Approved Maintenance Management Plan	CapeNature	Yes

Planned mouth breaching procedures

CapeNature is responsible for the operational aspects of the Heuningnes Estuary MMP. Although they may delegate this function they are ultimately responsible for the correct implementation of the breaching policy. To better formalise institutional arrangements, it is recommended that a Breaching Sub-committee be established as a formal institutional structure to co-ordinate the Breaching Sub-committee, which include:

- Convening Breaching Sub-committee meetings;
- Recording the minutes of the Breaching Sub-committee meetings;
- Distributing relevant information to the Breaching Sub-committee members; and
- Sharing the post-breaching incident report of the Breaching Sub-committee.

CapeNature is also responsible for continuous monitoring of the conditions in the catchment when water levels become elevated (>2.0 m MSL). Communication between the different role players, i.e. the CapeNature, district municipality, and key authorities (stipulated in Section 4), should take place on a regular basis. This can be done at through a virtual meeting, an advisory committee/forum meeting or as email communications among these parties summarising critical aspects. The day-to-day monitoring should include the following aspects:

- Actual and predicted rainfall in the catchment;
- Water levels in the estuary and its rate of increase;
- Height and width of the sand berm at the mouth;
- Actual and predicted wave conditions;
- Availability of equipment to breach the mouth;
- Water quality conditions (where and if applicable); and
- Biotic responses to elevated water levels (e.g. fish aggregations at mouth, formation of algal blooms, die-back of macrophytes, bird nesting behaviour).

Once the breaching criteria (see Section 5) are met, the decision to artificially breach will be made by the Breaching Sub-committee (See Section 4 for list) comprising presence of, as a minimum, the CapeNature De Mond Nature Reserve Manager, the Landscape South Manager, the Marine and Coasts Operations Manager, and at least two qualified estuarine ecologists (e.g. from DFFE: Inshore Fisheries Research and DFFE: Estuaries Management and/or private sector). Note, that while the Breaching Sub-committee is tasked with executing the approved MMP, it should be recognized that an estuary mouth is highly dynamic and unforeseen events may require special management actions. In such an event, additional verbal (followed by written) authorisation may be required from the authorising authority (i.e. DFFE). A flow chart of the procedures for a planned mouth breaching is presented in Figure 2.

Once the Breaching Sub-committee has established that the relevant criteria have been met and that artificial breach must occur, CapeNature shall be responsible for overseeing the breaching activities.

Cape Nature is responsible for the following:

- Ensuring the availability of earth moving equipment on day of breaching;
- Establishing the exact location of the breaching channel;
- Verifying that the sandberm at the mouth is high enough above the water line so that there is no risk of “fluidization” of berm sediment (i.e. turning to quicksand when breaching starts) and become a hazard to the operator and equipment;
- Deploying flags and signage to warn the public of the safety risks safety; and
- Breaching of the estuary mouth.

The DeMond Nature Reserve Manager is responsible for the compilation of a Breaching Incident Report to be submitted to DFFE within 14 days of the breaching activity (see Section 8 for more detail on the report).

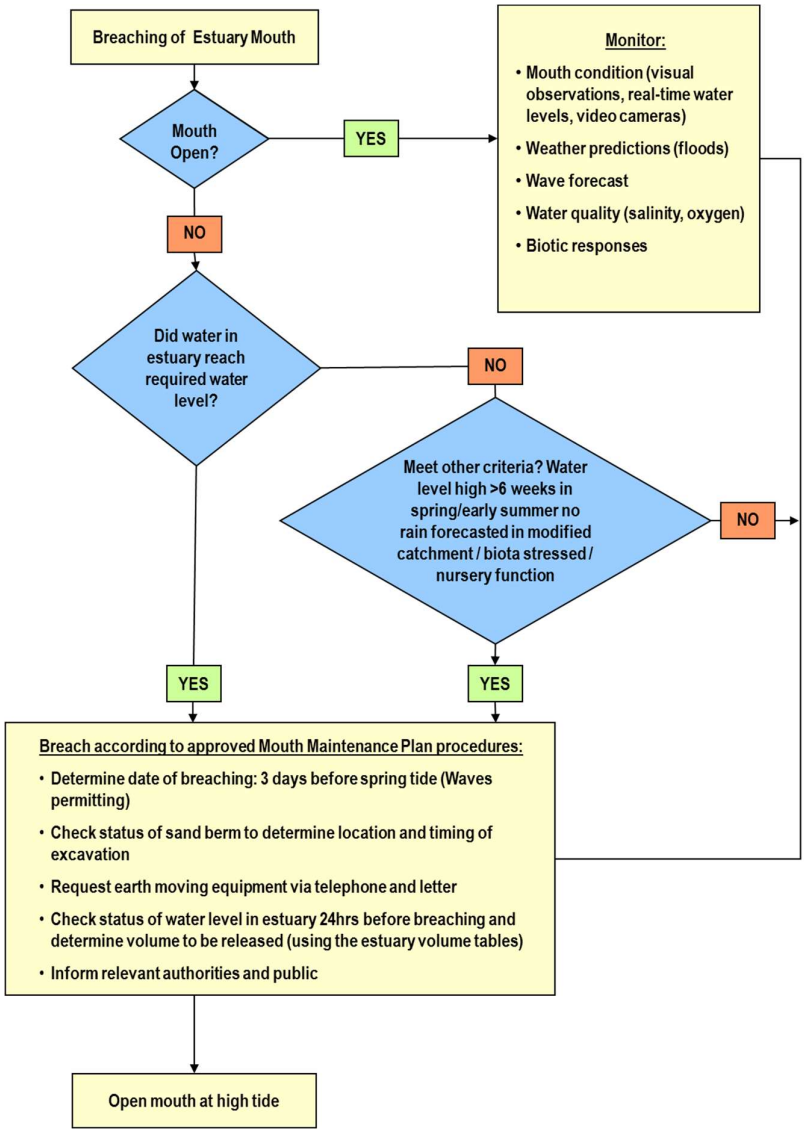


Figure 2: A flow chart of the procedures for a planned mouth breaching

Emergency

Emergency conditions could develop when an estuary mouth is closed/constricted and severe rainfall occurs in the catchment causing a large flood. Alternatively, they could also develop at the (largely unlikely) event of a break of the dam wall. Constant monitoring of the conditions in the catchment is required when emergency conditions develop. Communication between the different role players, i.e. CapeNature, the local and district municipalities, and key authorities (DFFE) involved, should take place, if time is available, to monitor the situation. Included in the monitoring are:

- The actual and expected rainfall in the catchment.
- The water level in the estuary and its rate of increase.
- The height and width of the sand berm at the mouth.
- The actual and predicted wave conditions.
- The availability of equipment to breach the mouth on short notice.

A flow chart for the procedures to be followed during emergency breaching is provided in Figure 3. Such breachings should be undertaken in the swiftest manner possible. In most cases the Disaster Risk Department of the local municipality will be the responsible authority but for the Heuningnes estuary this will most likely be CapeNature. While breaching should be conducted according to an approved Mouth Maintenance Management Plan, some of the general breaching principals may be waivered under such emergency conditions to ensure an expedient breaching.

While most emergency breachings are usually linked to river floods, Section 3 lists some additional events that can trigger an emergency mouth breaching in the case of the Heuningnes Estuary.

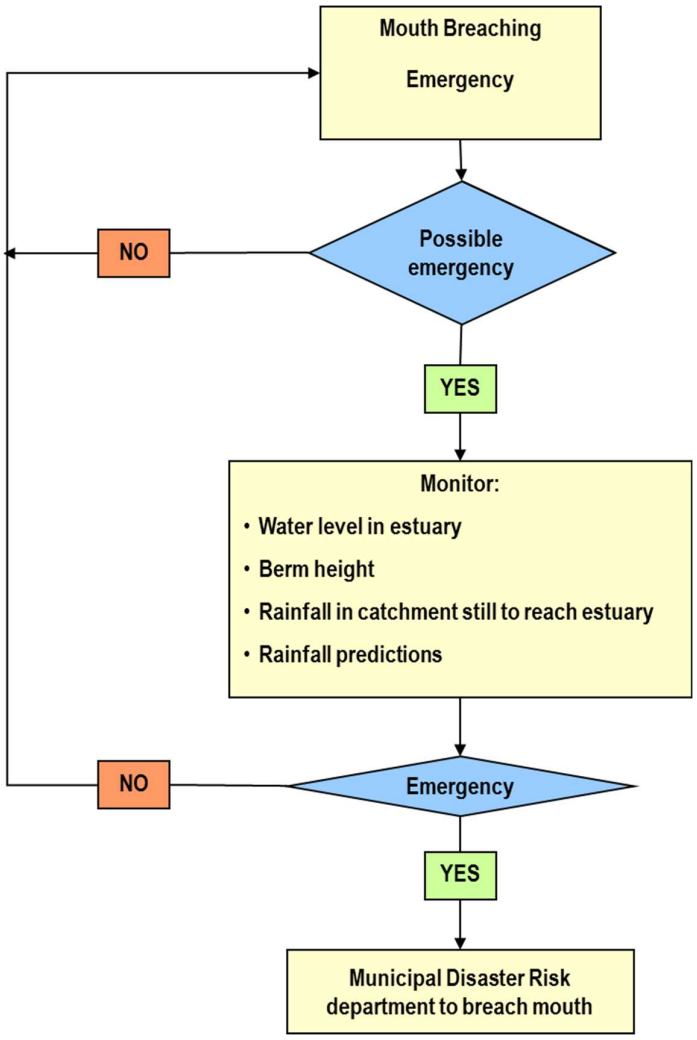


Figure 3: A flow chart of the procedures of an emergency breaching plan

MONITORING PROGRAMME

The following monitoring programme is required to be able to perform artificial breaching in a responsible and effective manner (Table 5):

Table 5: Monitoring programme for Heuningnes Estuary relating to artificial breaching

MONITORING ACTIONS	FREQUENCY	LOCAL REQUIREMENT - YES/NO	AGENCY RESPONSIBLE
Weather forecast	Period leading up to breaching	Yes	SA Weather Services
Water levels	Continuous	Yes	DWS
River inflow data	Daily	Yes	DWS

Bathymetric surveys	Every 3 years	Yes	CapeNature
Salinity (quarterly)	Monthly (and just before and after breaching breaching)	Yes	CapeNature
In situ water quality measurements (e.g. oxygen)	Monthly	Yes	CapeNature
Berm levels	Monthly (and just before breaching)	Yes	CapeNature
Visual observations on estuarine vegetation (e.g. checking for inundation of salt marsh, reeds & sedges and occurrence of nuisance algal blooms)	Quarterly (and just before breaching)	Yes	CapeNature
Visual observations on Invertebrate behaviour (e.g. checking for invertebrate kills)	Quarterly (and just before breaching)	Yes	CapeNature
Fish surveys (Distribution, abundance) Visual observations on fish movement and behavior (e.g. recruitment, aggregations, fish kills)	Bi-annually	Yes	CapeNature/DFFE
Co-ordinated Water bird Counts (CWAC)	Bi-annually	Yes	CapeNature

REPORTING

Following a breaching, a Breaching Incidence Report needs to be compiled by CapeNature (DeMond Reserve Manager) and submitted to DFFE within 14 days of the activity. This report should contain as much as possible information on the motivation for breaching and the process followed.

In addition to the Breaching Incidence Report, CapeNature needs to compile an Annual Breaching Report that summarises information on all mouth manipulation activities during a year, including a review of ecological responses and consequences to human well-being and safety. The Annual Breaching Report needs to be presented to all Interested and Affected Parties (I&AP) (relevant authorities and civil society) to communicate progress with the implementation of the MMP. Such feedback sessions provide the opportunity for a critical review of current breaching practises and discussions on possible future improvements to the MMP.

Breaching Report

Table 6 below summarises the minimum content of a Heuningnes Estuary Breaching Incidence Report. The initial report should be complied within about 14 days of the breaching activity, with data gaps (e.g. duration open) addressed after mouth closure.

Table 6: Content of Estuary breaching report

ACTIONS	REQUIREMENT	AGENCY RESPONSIBLE
<u>Met-ocean information</u> • State of the tide (spring-neap/ high-low tide) • Sea conditions (calm/stormy)	Yes	CapeNature
<u>Estuary Information</u> • Water level from DWS (and volume) before breaching • Maximum outflow rate during breaching calculated from water levels and surface area of system • Outflow duration (from water level graph) • Lowest water level achieved after breaching (from water level graph) • Did flooding problems arise before or during the breaching? If so, quantify these problems. • Could measures be taken to prevent such problems in the future? For example by protection of low laying properties. Distinguish between short-term and long-term measures. • Could further problems arise by design of new developments at too low levels? • Date since last reaching • Estimated volume of sediment removed and indicate how sediment was disposed (e.g. left on berm at mouth). Were there problems with septic tanks before the breaching? If so quantify	Yes	DWS & CapeNature
<u>Location of breaching channel</u> • Align with historical position of channels • Reduce channel length • Estimated volume of sediment excavated during the breaching	Yes	CapeNature
Period the mouth stayed open	Yes	CapeNature
Bathymetric surveys before breaching events to establish erosion /deposition rates.	Yes	CapeNature
Salinity measurement before and after breaching	Yes	CapeNature
Macrophyte conditions	Yes	CapeNature
Fish recruitment survey	Yes, in summer after breaching	DFFE and CapeNature
Avifuana counts (CWAC)	Yes	CapeNature
Other		
<u>Assessment record compiled by:</u> Name: Organization: Date: Contact details:		

Feedback on breaching activities

Table 7 below summarises the minimum information required as evidence of feedback breaching activities to the relevant authorities and stakeholders. Such report back sessions should be held at least once a year to ensure that the correct breaching procedures are being followed and that additional interventions are not required.

Table 7: Minimum information to be captured at breaching feedback sessions

ACTIONS	REQUIREMENT -
Responsible agency /authority	CapeNature
Place & Workshop venue	
Date	
Meeting/committee/workshop participants (attached attendance register)	
Workshop chaired by	
Key lessons learned that could assist with future breaching	
Material presented at meeting (including copies of presentations)	
Assessment record compiled by: Name, Organization, contact details:	
Workshop venue, town, date:	
Workshop chaired by:	
Attendance register provided	

REFERENCES

Anchor Environmental Consultants 2018. Determination of the Ecological Reserve for the Heuningnes Estuary. Report prepared for the Breede-Gouritz Catchment Management Agency. 210 pp.

Bickerton, I 1984. Estuaries of the Cape. Part II Synopsis of available information on individual system. Report 25: Heuningnes (CWS19). CSIR Research Report 424. Stellenbosch, South Africa.

Geldenhuys, D 2020. Heuninges Estuary breaching report. Internal CapeNature Report.

Gordon, N. 2012. The past and present limnology of the Soetendalsvlei wetlands, Agulhas Coast, South Africa. PhD thesis, Nelson Mandela Metropolitan University, Port Elizabeth.

Hoestra, T. & Waller, L. 2014. De Mond Nature Reserve Complex. Protected Area Management Plan. Unpublished report, CapeNature, Cape Town.

Kotsedi, D. 2007. Emergent macrophytes as an indicator of past and present ecological conditions in Soetendalsvlei. Unpublished Honours research project, Department of Botany, Nelson Mandela Metropolitan University, Port Elizabeth. 48 pp.

SMEC 2017. Heuningnes Estuary Hydrodynamic Modelling, Flood Line Delineation and Mouth Management Recommendations. Unpublished report prepared for Cape Nature, 50 pp.

Turpie JK 2004. South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 3: Estuaries Component. Pretoria: South African National Biodiversity Institute.

Turpie, J. & Clark, B. 2007. The health status, conservation importance and economic value of temperate South Africa estuaries and the development of a regional conservation plan. C.A.P.E. Estuaries Conservation Plan. Anchor Environmental Consultants, Rhodes Gift.

Turpie, J.K., Taljaard, S., van Niekerk, L., Adams, J., Wooldridge, T., Cyrus, D., Clark, B. & Forbes, N. 2012. The Estuary Health Index: a standardised metric for use in estuary management and the determination of ecological water requirements. WRC Report No. 90 pp.

Underhill, L.G. and Cooper, J. 1983. Counts of waterbirds on the coastline of southern Africa, 1976-1983. Cape Town: Western Cape Wader Study Group and Percy FitzPatrick Institute of African ornithology.

Van Niekerk, L. & Turpie, J.K. (eds) 2012. South African National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. CSIR Report Number

CSIR/NRE/ECOS/ER/2011/0045/B. Council for Scientific and Industrial Research, Stellenbosch.