BREEDE-GOURITZ CATCHMENT MANAGEMENT AGENCY

Determination of the Ecological Water Requirements for the Klein Estuary

September 2015

ANCHOR environmental

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This report should be cited as:

Anchor Environmental Consultants 2015. Determination of the Ecological Reserve for the Klein Estuary. Report prepared for the Breede-Gouritz Catchment Management Agency. 197 pp.

APPROVAL

TITLE:	Determination of the Ecological Water Requirements for the Klein Estuary
DATE:	September 2015
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FORMAT:	MSWord and PDF
WEB ADDRESS:	http://breedegouritzcma.co.za/

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EXECUTIVE SUMMARY

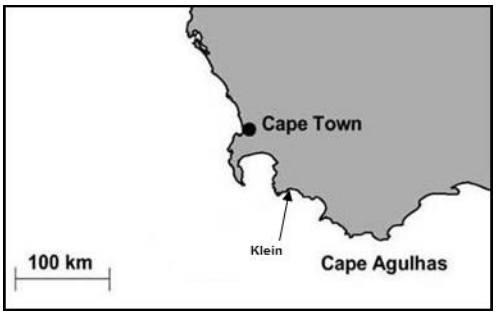
Introduction

This study was commissioned to determine the Ecological Reserve for the Klein estuary, which entails following a set of procedures to determine the Present Ecological Status (health state), the Recommended Ecological Category (the future state of health) and the quantity and quality of freshwater inflows and other conditions required to maintain this. The analysis involved estimating the characteristics of the system in its original condition as well us under a range of potential future scenarios.

Location and delineation of the Klein estuary

The Klein Estuary is situated more or less midway between Cape Point and Cape Agulhas on the south-west coast within the cool temperate biogeographic region of South Africa. It enters the sea at 34°24'58”S 19°17'35”E (Whitfield 2000). The geographical boundaries for the study are defined as follows:

Downstream boundary:	Estuary mouth 34°24'58”S 19°17'35”E
Upstream boundary:	34°25'53"S, 19°27'30"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank



Map of the south western tip of South Africa, showing the position of the Klein Estuary

Geographical boundaries of the Klein Estuary

Baseline description and health assessment

Overall context and pressures

The Klein catchment lies in the Breede-Overberg Water Management Area, within the Overberg District Municipality in the Western Cape Province . The estuary is located within the Overstrand Local Municipality. The total quaternary catchment area according to WR2005 is 983 km^2. There is significant commercial (mostly dryland) agriculture in the catchment, mostly in the upper parts. There are also a number of intensive feed farming agricultural sites close to the estuary. The density of development around the estuary is generally low with the exception of the nodal urban areas of Hermanus and Stanford and some resorts on the estuary itself. Key factors influencing the quality and quantity of flows into the estuary were identified as water use for irrigation, agricultural and pastoral run-off containing fertilisers, pesticides and herbicides, effluent from the Stanford WWTW (organic and inorganic nutrient loading), septic and conservancy tank seepage from developments on the banks of the estuary, and litter. The Klein estuary is used extensively for recreational purposes and is a popular venue for sailing, canoeing, kite surfing. Considerable development exists below the 1:50 year flood line, some of which is threatened by back flooding when the mouth is closed. Affected landowners then pressurise the authorities to artificially breach the system or someone tale matters in to their own hands. Poaching of marine organisms in the Overstrand area, particularly the use of illegal gill nets to trap fish in the Klein estuary, is also of high concern.

Hydrology

The Natural MAR for the Klein River catchment is estimated at 68.1 million m^3/a based on data from WR2005. A portion of the runoff from the lowest sub-catchment (G40L) flow directly to the sea and not into the estuary. Thus, the total Natural MAR for the estuary was estimated at 53.41 Mm^3/a. There are also no major dams within the Klein catchment, however, there are numerous farm dams that are used to supply water for irrigation. An estimated 8.69 M m/a is abstracted from the system for irrigation, while abstraction for industrial and domestic supply is estimated at around 0.444 million m^3/a. The impact of invasive alien plants in the Klein River catchment is considered to be extreme, and accounts for a further reduction 6.5 Mm^3/a. The Present Day MAR is thus estimated at 40.88 Mm^3/a, or 77% of Natural. As an estuarine lake system, the Klein estuary is sensitive to any change in inflows. Thus, hydrological health was assessed on the basis of the overall change in MAR between Reference and Present, and was allocated a score of 77%.

Present health score: 77

Physical habitats

Sediments in the Klein Estuary are derived from three main sources: the river, the sea and bank erosion. Historically, the Klein River delivered a relatively low sediment load into the estuary, most of which was fine sediment. The significant agricultural activities in the catchment have, however, led to increased land erosion and thus sediment yield to the estuary. Other drivers of change in the Klein estuary were identified as:

- Reduction in floods as a result of water abstraction from the catchment,
- Increased sediment input from the river catchment,

- Clearing of riparian vegetation, riparian development, agricultural livestock grazing and trampling,
- Road, riparian and instream infrastructure, and
- Alien vegetation in the supra-tidal zone.

Overall, it was concluded that there has been a modest change in supratidal habitats, little change in intertidal habitats, and significant change in subtidal habitats and bathymetry at the point where the river enters the main body of the lagoon and near the mouth but little change elsewhere.

Physical habitat score: 65

Hydrodynamics and abiotic states

Changes in river inflow and artificial breaching were judged to have resulted in major changes in the mouth condition, water level, salinity distribution, and water quality in the Klein estuary. Artificial breaching at lower than natural breaching levels, has resulted in a reduction in the volume and duration of water flow out to sea, which in turn has reduced sediment scouring. This has disrupted the long-term erosion/depositional cycles in the estuary, resulting in increased sedimentation in the lower estuary. Under the reference state the estuary was estimated to open for about 30% of the time, but under Present day conditions this has dropped to around 22% of the time. The occurrence of different abiotic states in the estuary have also changed: the amount of time that the estuary is in an “Open marine” and “Closed brakish” states has decreased while the “Closed marine” state has increased.

Hydrodynamics and mouth condition health score: 72

Water quality

Water quality parameters considered important in estuaries includes salinity, temperature, pH, turbidity, dissolved oxygen, inorganic nutrients and toxic substances (pesticides, trace metals, etc.). Salinity is thought to have increased slightly overall due to the observed reduction in flow between the Reference and Present states; there has been a marked increase in nutrient input from anthropogenic sources (e.g. agriculture and WWTW effluent) from Reference to Present, but no marked changes in turbidity. Increases in organic loading and nutrient input from anthropogenic sources (e.g. agriculture and WWTW effluent) have caused eutrophication of the system with a resultant drop in oxygen levels and occasional hypoxic events. Although no data are available to confirm this, it is also considered likely that agriculture in the catchment and urban development along banks has resulted in an increase in toxic substances in the estuary (herbicides and pesticides in the case of the former and metals and hydrocarbons, in the case of the latter).

Water quality health score: 81

Microalgae

There is very little data available for microalgae on the Klein estuary. Available data and expert opinion does however suggest that water column chlorophyll-a (phytoplankton biomass), particularly in the upper reaches, has increased as a result of reduced base flows and an increase in closed mouth conditions together with high nutrient inputs, and that some pollution intolerant microalgae species and those species associated with the open marine phase may have been lost. Blue-green algae, on the other hand, have increased as they are able to outcompete other algal groups under nutrient rich, brackish conditions.

Microalgae health score: 65

Macrophytes

The distribution of different habitats within the estuarine functional zone (5 m topographical contour) was mapped from the 1938, 1980 and 2014 aerial images obtained from National Geo-Spatial Information (Surveys and Mapping) and compared with other available mapping data for the estuary (De Decker 1989, Turpie and Clark 2007). Change in macrophyte habitat from the Reference condition was determined through visual comparison of these images. Key findings from this assessment indicate that macrophyte species richness in the estuary has declined due to a reduction in baseflows reaching the estuary and the concomitant increase in salinity as well as due to encroachment by development, disturbance and invasive species. A critically endangered species *Cotula myriophyllodes* may have been lost from the estuary. Some macrophyte habitat (35 ha) has clearly been lost due to development, agriculture and invasive species. Large areas of the floodplain (110 ha) have been disturbed by human activity. Nutrient enrichment has encouraged growth of macroalgae which in turn has resulted in a loss in area covered by submerged macrophytes due to shading. Increases in salinity and development of saltpans have also caused a reduction in the density and cover of salt marsh plants.

Macrophyte health score: 70

Invertebrates

Very little research has been undertaken on the invertebrate communities of the Klein estuary and almost no quantitative data exists for this group. Scott *et al*. (1952) provided a qualitative account of the invertebrate fauna of the estuary and included a species list of taxa present at the time. Stations sampled by Scott *et al.* (1952) were resurveyed as part of this study in an effort to assess the health of this component under Present day conditions. These data suggest that there has been a loss of stenohaline marine species from mouth region, but that overall diversity remains high with little change in community composition from the Reference state. Species that prefer increased macrophyte growth on floodplain (e.g. *Exosphaeroma, Cyathura estuaria* and *Talorchestia*) have most likely proliferated though. The abundance and biomass of large burrowing species have declined (probably largely due to bait collecting) and has result in a significant shift in the overall estuary community structure.

Invertebrate health score: 70

Fish

Estuaries provide an extremely important habitat for fish in southern Africa. The vast majority of coastal habitat in southern Africa is directly exposed to the open ocean, and as such is subject to intensive wave action throughout the year. Estuaries in southern Africa are thus disproportionately important relative to other parts of the world, in that they constitute the bulk of the sheltered, shallow water inshore habitat in the region. Fish fauna of the Klein estuary have been intensively sampled over the last 15 years (2000-2015), and a good deal of information is available. A total of 51 fish species from 27 families have been recorded. Near half (45% or 23 species) of these are entirely dependent on estuaries to complete their lifecycles, while another 10 (20%) are at least partially dependent on estuaries. Overall, the fish fauna were judged to be broadly similar to the Reference condition. Some estuarine-dependent species are present in very low numbers, though, and are functionally absent from the estuary. At least 6 alien species have colonised the upper reaches of the system. Marine species are largely absent from the estuary. Numerically dominant *A. breviceps* and *G. aestuaria* have not changed much since Reference but there has been a severe drop in recruitment and survival of estuarine-dependent marine species in the system, probably as a result of gill net poaching.

Fish health score: 60

Birds

Data on birds of the Klein estuary include a count from 1981, annual CWAC counts from 2001-2012 some anecdotal historic information, and some monthly counts undertaken in recent years. In total, 71 waterbird species have been recorded on Klein Estuary. The highest numbers of species recorded in any single count was 44 counted in January 1981, and 40 in February 2003 and March 2004. The overall abundance of birds seems to have decreased from the 1976 and 1981 surveys (5406 waders only and 9974 waterbirds, respectively) until the most recent comparable summer survey (February 2002 – 2007 birds). The composition recorded during the recent summer CWAC surveys was quite different from that recorded in January 1981. In the earlier survey, the community had a higher proportion of gulls and terns (89%), mainly due to very high numbers of the migratory Common Tern. The herbivorous waterfowl component of the community was the second most abundant group in 1984 but numbers have been relatively low in recent counts. During 2001-2012, the avifauna of the Klein Estuary was dominated by piscivorous gulls and terns (40%) and herbivorous waterfowl (22%) in summer, with the former group being dominated by the migratory Common Tern. In winter, the bird community was heavily dominated by herbivorous waterfowl (76%). These were mainly Red-knobbed Coot, which was by far the most common bird on the estuary. The numbers of waders are higher in summer due to an influx of migrants. The numbers of omnivorous waterfowl are also higher in summer, when fresh and brackwater areas are scarcer than in winter in this winter rainfall area. Overall, the Present health of the water bird community of the Klein estuary was judged to be poor.

Bird health score: 21

Present ecological status

Table 1 summarises the above findings. The EHI score for the Klein Estuary in its present state was estimated to be 65 (i.e. 65% similar to natural condition, which translates into a Present Ecological Status (PES) of C. This arises from significant changes in the hydrology (MAR), mouth status, water quality, microalgae and bird fauna.

Table I. Present ecological status of the Klein Estuary

Variable	Health score/100	Health score net of non-flow related impacts	Confidence score	Confidence
Hydrology	77	77	70	Med
Hydrodynamics and mouth condition	72	93	50	Low
Water quality	81	98	70	Med
Physical habitat alteration	65	97	50	Low
Habitat health score	**68**	**91**	**60**	**Low**
Microalgae	65	83	50	Low
Macrophytes	70	76	70	Med
Invertebrates	70	76	50	Low
Fish	60	80	50	Low
Birds	21	64	50	Low
Biotic health score	**57**	**76**	**54**	**Low**
ESTUARY HEALTH SCORE	**65**	**83**	**57**	**Low**
PRESENT ECOLOGICAL STATUS	**C**	**B**		
OVERALL CONFIDENCE	**Low**			

Relative contribution of flow and non-flow related impacts on health

Estimates of the contribution of non-flow related impacts on the level of degradation of each component led to an adjusted health score of 83, which would raise the PES to a B category. This suggests that non-flow impacts have played a major role in the degradation of the estuary to a C, but that flow-related impacts are still an important cause of its degradation. Thus the highest priority is to address the quantity and quality of influent water. Of the non-flow-related impacts, elevated nutrient inputs from the catchment and artificial breaching of the mouth of the estuary were found to be the most important factors that influenced the health of the system.

Overall confidence

Confidence levels were very low for two of the abiotic components (Hydrodynamics and mouth condition and Physical habitat alteration) and most of the biotic components (all except macrophytes). This most mostly due to the lack of historic information (i.e. the state of the estuary under Natural conditions). The overall confidence of the study was Low.

The implications of this are that

(a) one has to be extremely cautious and apply the precautionary principle in setting the Preliminary Reserve; and
(b) efforts should be made to collect baseline and monitoring data that will help to fill some key gaps in understanding.

Recommended Ecological Category (REC)

Conservation importance

The Estuary Importance Score (EIS) for the estuary takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account, and the overall score was 93, which corresponds to a rating of "Highly important" (Table II).

Table II. Importance scores (EIS) for the Klein estuary.

Criterion	Weight	Score
Estuary Size	15	15
Zonal Rarity Type	10	10
Habitat Diversity	25	25
Biodiversity Importance	25	25
Functional Importance	25	25
Weighted Estuary Importance Score		**93**

Recommended Ecological Category

The PES for the Klein is a C. The estuary is rated as "Highly important", and it is a designated as a desired protected area in the Biodiversity Plan for the National Biodiversity Assessment (Turpie *et al*. 2012). Thus the **Recommended Ecological Category** for the estuary is an "A" or its "Best Attainable State".

Operational and ecological reserve scenarios

Although there are no firm plans for increased utilisation of water in the Klein River catchment, a number of hypothetical scenarios were constructed to examine likely impacts of further decreases (transfers out of the catchment) as well as some increases (restoration) in flow on the health of the Klein estuary. Restoration in flows was assumed to be achieved through removal of Invasive Alien Plants (IAPs) and or reduction in water use for irrigation. The following scenarios were considered:

- Scenario 1: + 20% of Present (i.e. 16% reduction from Natural)
- Scenario 2: + 10% of Present (i.e. 26% reduction from Natural)
- Scenario 3: - 10% of Present (i.e. 46% reduction from Natural)
- Scenario 4: - 20% of Present (i.e. 56% reduction from Natural)
- Scenario 5: - 30% of Present (i.e. 66% reduction from Natural)
- Scenario 6: - 40% of Present (i.e. 66% reduction from Natural)

A summary of changes in MAR under each of these scenarios is presented in Table III below.

Table III. Summary of the scenarios evaluated in this study.

Scenario name	Description	MAR (x 10^6 m^3)	Percentage remaining
Natural	Reference condition	53.41	100%
Present	Present day	40.88	76.55
Scenario 1	+ 20% of Present (remove all IAPs, reduce irrigation by 46%)	52.08	97.51
Scenario 2	+ 10% of Present (remove all IAPs)	49.43	92.56
Scenario 3	- 12% of Present (i.e. 33% reduction from Natural)	40.00	74.90
Scenario 4	- 21% of Present (i.e. 40% reduction from Natural)	36.17	67.73
Scenario 5	- 28% of Present (i.e. 49% reduction from Natural)	31.45	58.90
Scenario 6	- 41% of Present (i.e. 55% reduction from Natural)	28.03	52.48

Estuarine Health Index Scores and corresponding Ecological categories for the various abiotic and biotic components of the estuary are presented in Table IV.

Table IV. EHI score and corresponding Ecological Category under the different runoff scenarios

	Wt	Pre-sent	1	2	3	4	5	6	Conf
Hydrology	25	77	98	93	75	67	59	53	M
Hydrodynamics and mouth condition	25	72	84	78	62	43	37	28	L
Water quality	25	81	80	80	80	67	55	38	M/L
Physical habitat alteration	25	65	65	65	65	65	55	50	L
Habitat health score		**68**	**74**	**72**	**65**	**58**	**51**	**40**	**L**
Microalgae	20	65	60	60	55	45	40	35	L
Macrophytes	20	70	80	75	60	50	40	30	M
Invertebrates	20	70	95	90	55	50	40	30	L
Fish	20	60	65	60	60	50	40	35	M
Birds	20	21	23	22	19	16	12	9	
Biotic health score		**57**	**65**	**61**	**50**	**42**	**34**	**28**	**L**
ESTUARY HEALTH SCORE		**65**	**72**	**70**	**60**	**51**	**43**	**35**	**L**
PRESENT ECOLOGICAL STATUS		**C**	**C**	**C**	**D**	**D**	**D**	**E**	
EHI after non-flow impacts removed		**91**	**94**	**94**	**90**	**86**	**84**	**81**	
PES after non-flow impacts removed		**A**	**A**	**A**	**B**	**B**	**C**	**C**	

Recommended ecological flow requirement

For a high confidence study, the **'recommended Ecological Flow Requirement' scenario,** is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the recommended Ecological Category. Where any component of the health score is less than 40, then modifications to flow and measures to address anthropogenic impacts must be found that will rectify this. For lower confidence studies, such as this one, a more conservative flow scenario (or a slight modification thereof to address low-scoring components) should be chosen, using the following guidelines.

Based on this assessment, the Best Attainable State for the Klein estuary is considered to be a B (one class higher than Present). Attaining this state would require restoring a certain amount of flow to the system as well as addressing some of the existing non-flow related issues affecting the estuary.

Two scenarios were considered in this study in which flows to the Klein estuary were restored towards natural – Scenario 1 and 2 (Table III). Scenario 1 entailed increasing Present Day flows by 20% - i.e. restoring flows to within 97.5% of Natural. This would require removing all Invasive Alien Plants (AIPs) from the catchment and reducing irrigation use by 46%. This is unfortunately not considered feasible. Scenario 2 is more realistic as it entailed increasing flows relative to Present Day by 10% - i.e. to within 92.6% of Natural. This could be achieved by removing all AIPs from the catchment or by removing the majority of these AIPs and through modest improvements in irrigation efficiency and/or eliminating some illegal use. This is considered to be entirely feasible.

Thus, it was agreed that the flow requirements for the estuary are the same as those described for Scenarios 2. A summary of the monthly flows for these two scenarios is presented in Table V.

Table V. Summary of the monthly flow (in $m^3.s^{-1}$) distribution under Scenario 2 and 3

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	31.86996	15.85168	6.82348	3.78748	16.33256	10.99668	62.07284	33.07472	52.09756	50.2228	60.37216	50.09532
90%ile	8.2754	3.933	0.638	0.1666	0.1362	0.3282	3.728	10.6746	14.8056	22.8882	31.644	9.7088
80%ile	4.3728	1.9586	0.192	0	0	0.1162	0.8012	3.5836	8.6336	9.4298	19.2116	6.5028
70%ile	2.683	1.0472	0.1046	0	0	0	0.31	1.495	5.1348	5.1652	11.852	4.8286
60%ile	2.2786	0.7646	0.0746	0	0	0	0.117	0.593	2.578	3.7004	8.6844	4.007
50%ile	1.786	0.521	0.053	0	0	0	0.029	0.388	1.214	2.533	6.107	3.255
40%ile	1.5044	0.4394	0.0366	0	0	0	0	0.151	0.7078	1.821	4.3002	2.6678
30%ile	1.1952	0.3604	0.0244	0	0	0	0	0.0586	0.3022	1.4138	2.6404	2.21
20%ile	0.935	0.2876	0.0024	0	0	0	0	0	0.2274	0.9148	1.6672	1.7758
10%ile	0.5814	0.1934	0	0	0	0	0	0	0.0758	0.4978	0.737	1.2982
1%ile	0.32588	0.06452	0	0	0	0	0	0	0	0.10384	0.35336	0.42724

Removing AIPs from the Klein catchment would require concerted effort by both government and non-government stakeholder, including the following agencies/stakeholder:

- Department of Water and Sanitation (DWS)
- Breede Overberg Catchment Management Agency
- Cape Nature
- Overstrand Municipality
- Private landowners

An audit of all water use in the Klein catchment should be undertaken by BOCMA as a priority first step in order to identify and all legal and illegal uses of water in the catchment, to quantify their level of use. Thereafter, steps need to be taken to eliminate all illegal abstractions and to ensure legal users do not exceed their allowable limits.

There are also a number of equally important non-flow related interventions that need to be implemented by the respective authorities, landowners and other stakeholders that will assist in restoring the Klein estuary to a "B" category. These interventions are listed in Table VI Table 6.3along with the agencies/individuals identified as being able assist with these interventions.

Table VI. Priority non-flow related interventions that need to be implemented by the respective authorities, landowners and other stakeholders to improve the health status of the Klein estuary to a "B" class.

Measure	Responsibility
1. Reduce levels of inorganic nutrients in inflowing water from the catchment	
• Reduction in fertilizer use in the catchment	Landowners, farmers
• Educate landowners/farmers on impacts of excessive fertilizer use on the Klein estuary	BOCMA, Cape Nature, Overstrand municipality
• Improve quality of effluent from Standford WWTW	Overstrand municipality
2. Reduce direct inputs of inorganic nutrient into the estuary	
• Eliminate septic and conservancy tanks from properties on the banks of the Klein estuary through provision of sewage reticulation infrastructure	Overstrand municipality
3. Implement a mouth management plan that satisfies ecological requirements of the estuary (increased breaching water level, improved nursery function, improved water quality, increase connectivity with the Botvlei Estuary through aligning open periods where possible)	Overstrand municipality, Department of Environmental Affairs & Development Planning
4. Institute and enforce appropriate development set-back line around the estuary that provide adequate protection for estuarine fauna and flora	Overstrand municipality, Department of Environmental Affairs & Development Planning
5. Management of recreational activities on the estuary through zonation to reduce impacts of kite boarding and sailing on bird populations	Overstrand municipality, Cape Nature
6. Improved compliance in respect of use of living marine and estuarine resources (legal and illegal fishing)	Department of Agriculture Forestry & Fisheries (DAFF), Overstrand municipality
7. Establish a statutory protected area that covers at least 50% of the estuary in accordance with recommendations tabled by Turpie *et al.* 2004, Turpie & Clark 2007, Turpie *et al*. 2012)	Department of Environmental Affairs (DEA), Cape Nature, Overstrand municipality
8. Motivate for Ramsar status to increase national and international awareness of this important estuary. The systems meats all the criteria for being declared a Ramsar site	Department of Environmental Affairs (DEA), Cape Nature

Resource quality objectives

Since the estuary has to be restored from a C to a B category, the thresholds of potential concern (TPCs) should be seen as targets to be met within 5 years. Thereafter the estuary should be maintained such that these thresholds are not breached. The TPCs for the Klein Estuary area listed in Tables VII and VIII.

Table VII. Ecological specifications and thresholds of potential concern for abiotic components

Abiotic Component	Ecological Specification	Threshold of Potential Concern
Water quality	Salinity structure and the occurrence of different abiotic states should correspond as closely as possible with the Reference condition; State 5 (Closed hypersaline) should not occur at all.	• % time in State 1 (Open, marine) drops below 10% • Salinity in any part of the estuary exceed 35
Hydrodynamics	Water quality of the influent water at the head of the estuary and in the estuary itself should approximate Reference conditions as closely as possible. Important risk factors include elevated pH and nutrient levels in the influent waters and low oxygen levels in the estuary especially at night.	• pH levels in influent waters at the head of the estuary rise above 7.5 • Dissolved Inorganic Nitrogen (DIN) levels in influent waters at the head of the estuary exceed 1000 µg/ℓ • Dissolved Inorganic Nitrogen (DIN) levels in influent waters at the head of the estuary exceed 30 µg/ℓ • Dissolved oxygen levels in the estuary drop below 4 mg/ℓ • Levels of contaminants (herbicides, pesticides, trace metals and hydrocarbons) in influent water at the head of the estuary or in the estuary itself exceed SA Water Quality Guideline levels
Sediment dynamics	Estuary should be allowed to function as naturally as possible within minimal human intervention	• Mouth is breached artificially when water level is <2.6 m • Amount of time mouth remains open drops below 22%, averaged over a period of 3 years

Table VIII. Ecological specifications and thresholds of potential concern for biotic components

Component	Ecological Specification	Threshold of Potential Concern
Microalgae	Phytoplankton biomass, measured as water column chlorophyll-a should not exceed 10 ug l^{-1}. Maintain high subtidal benthic microalgae biomass during the closed mouth phase and high intertidal benthic microalgae biomass during the open phase.	Phytoplankton biomass greater than 10 ug l^{-1}. Deviation in benthic microalgae biomass by 20 % compared with Present State concentrations. No brackish epipelic diatoms are found during the closed phase.
Macrophytes	Maintain the distribution of plant community types i.e. Submerged macrophyte, *Ruppia cirrhosa* beds during closed mouth brackish conditions, salt marsh, *Salicornia meyeriana* marsh during open mouth conditions, *Phragmites australis* stands in the middle/ upper reaches and salt marsh grasses indicative of brackish conditions.	Greater than 20% change in the area covered by different macrophyte habitats for baseline open and closed mouth conditions.
Benthic Invertebrates	The estuary should have viable populations of *Callianassa kraussi* in sandy zones and *U. africana* in muddy	Abundance of *C. kraussi* and *U. africana* drops below 50% of recorded total abundances in each season. No recruits in population

Component	Ecological Specification	Threshold of Potential Concern
Zooplankton	zones. Breeding in both species ceases at salinities lower than 17 ppt during prolonged mouth phase. In *U. africana* and export of larvae into marine and postlarvae back to estuary ceases. Prolonged close mouth would result in a loss of marine species (e.g. *Pseudodiaptomus* sp.*)* from the zooplankton community.	recorded. (Identify zones where these are abundant based from the study and these would be where the above would be assessed) Absence of indicator marine species (*Pseudodiaptomus sp.)* changes by more than 50% of current levels (still to be determined).
Fish	Retain the following fish assemblages in the estuary (based on abundance): estuarine species (20-30%), estuarine associated marine species (60-70%) and indigenous freshwater species (<1%). All numerically dominant species are represented by 0+ juveniles.	Level of estuary associated marine species drops below 50% of total abundance. Level of estuarine species increases above 50% of total abundance. Occurrence of alien freshwater species in the estuary. Absence of 0+ juveniles of any of the dominant fish species.
Birds	The estuary should contain a rich avifaunal community that includes representatives of all the original groups, significant numbers of migratory waders and terns, as well as a healthy breeding population of resident waders. The estuary should support thousands of birds in summer and hundreds in winter.	Numbers of waterfowl drop below 600, waders below 100 in summer, and terns below 250 Overall numbers of bird species drop below 1000 for 3 consecutive counts.

Monitoring requirements

Recommended minimum monitoring requirements to ascertain impacts of changes in freshwater flow to the estuary and any improvement or reductions therein are listed in Table IX.

Table IX. Recommended minimum requirements for long term monitoring

Ecological Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. Stations)
Hydrodynamics	Record water levels	Continuous	DWA station G4R004 (Yacht Club Jetty)
	Measure freshwater inflow into the estuary	Continuous	At the head of the estuary
	Aerial photographs of estuary (spring low tide)	Every 3 years	Entire estuary
Sediment dynamics	Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detailed in the mouth (every 100m). The vertical accuracy should be about 5 cm.	Every 3 years	Entire estuary
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)	Every 3 years (with invert sampling)	Entire estuary
Water quality	Collect data on conductivity, temperature, suspended matter/turbidity, dissolved oxygen, pH, inorganic nutrients and organic content in river inflow	Monthly continuous	At river inflow
	Assess and better quantify wastewater input (e.g. nutrients and organics) from diffuse sources (e.g. caravan park, WWTW).	Once-off detailed Possibly long-term (e.g. peak seasons) if input remains significant (preferably these should be mitigated)	In stream (source/s)
	Record longitudinal salinity and temperature profiles (and any other in situ measurements possible e.g. pH, DO, turbidity)	Seasonally, every year	Entire estuary (12 stns)
	Take water quality measurements along the length of the estuary (surface and bottom samples) for system variable (pH, dissolved oxygen, suspended solids/turbidity) and inorganic nutrients in addition to the longitudinal salinity and temperature profiles	Seasonal surveys, every 3 years or when significant change in water inflows or quality expected	Entire estuary (12 stns)
Microalgae	Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. HPLC or fluoroprobe. Intertidal and subtidal benthic chlorophyll-a measurements.	Summer and winter survey every 3 years	Entire estuary (5 stns)

Ecological Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. Stations)
Macrophytes	Ground-truthed maps; Record number of plant community types, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit; Record percentage plant cover, salinity, water level, sediment moisture content and turbidity on a series of permanent transects along an elevation gradient; Take measurements of depth to water table and groundwater salinity in supratidal marsh areas.	Summer survey every 3 years	Entire estuary (5 stns)
Benthic Invertebrates	Record species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary. Record benthic invertebrate species and abundance, based on van Veen type grab samples in subtidal and core samples in intertidal at a series of stations up the estuary, and counts of hole densities. Measures of sediment characteristics at each station	Summer and winter every 3 years	Entire estuary (6 stns)
Zooplankton	Record species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary.	Summer and winter every 3 years	Entire estuary (5 stns)
Fish	Record species and abundance of fish, based on seine net and gill net sampling.	Summer and winter survey every 3 years	Entire estuary (6 stns)
Birds	Undertake counts of all water associated birds, identified to species level.	A series of monthly counts, followed by winter and summer survey every year	Entire estuary (43 sections)

ACKNOWLEDGEMENTS

The follow persons and organisations are thanked for their contribution(s) to this study:

- The Breede Overberg Catchment Agency (BOCMA), and Cape Nature for funding the study;
- Pierre De Villiers for his support throughout the study and for contributions made at the RDM workshop;
- Staff at the South African Shark Conservancy in Hermanus for assistance with the invertebrate field surveys;
- Piet Huizinga for his insights and years of collaboration on the Klein Estuary;
- Sue Matthews for providing data and input on the water quality component of this study; Mr Ed Lucas for monitoring data on the Klein estuary berm heights and salinity distribution; and
- The Animal Demography Unit (ADU), the Department of Water Affairs & Sanitation (DWS), and the Overstrand Municipality for providing data for this study.

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ACRONYMS AND ABBREVIATIONS

AMSL	Above Mean Sea Level
BAS	Best Attainable State
CD	Chief Directorate
CPUE	Catch-per-unit-effort
CSIR	Centre of Scientific and Industrial Research
DEA: O&C	Department of Environmental Affairs: Oceans and Coast
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphate
DO	Dissolved Oxygen
DRP	Dissolved Reactive Phosphate
DRS	Dissolved Reactive Silicate
DWA	Department of Water Affairs (now DWS)
DWAF	Department of Water Affairs and Forestry (now DWS)
DWS	Department of Water & Sanitation
EHI	Estuarine Health Index
EIS	Estuarine Importance Score
ERC	Ecological Reserve Category
EWR	Ecological Water Requirement
H	High
L	Low
M	Medium
MAR	Mean Annual Runoff
MSL	Mean Sea Level
NMMU	Nelson Mandela Metropolitan University
NWA	National Water Act (1998)
PES	Present Ecological Status
ppt	Parts per thousand
RDM	Resource Directed Measures
REI	River Estuary Interface
RQO	Resource Quality Objectives
SA	South Africa
SDF	Standard Design Flood
VL	Very low
WMA	Water Management Area

1 INTRODUCTION

1.1 Water Resources Management in South Africa

South Africa's National Water Act (NWA) (No. 36 of 1998) requires the implementation of four types of regulatory activities in order to make optimal use of the country's water resources while minimising ecological damage:

1. **Resource-directed measures**, i.e. defining a desired level of protection for a water resource, and on that basis, setting environmental flows and specific goals for the quality of the resource (the Resource Quality Objectives);
2. **Source-directed controls**, i.e. controlling impacts on the water resource through the use of regulatory measures such as registration, permits, directives and prosecution, and economic incentives such as levies and fees, to ensure that the Resource Quality Objectives are met;
3. **Managing demand** on water resources to keep utilisation within the limits required for protection; and
4. **Monitoring** the status of the country's water resources on a continual basis, to ensure that the Resource Quality Objectives are being met, and to enable us to modify programmes for resource management and impact control as and when necessary.

The objective of Resource Directed Measures (RDM) is to ensure the protection of water resources, in the sense of protecting ecosystem functioning and maintaining a desired state of health (integrity or condition) of aquatic and groundwater-dependent ecosystems. This objective is met through various processes, including the setting of 'environmental flows', known as the **Ecological Reserve** (the quantity and quality of water reserved to support ecosystem function).

Water resources (river reaches, wetlands, estuaries, etc.) must first be classified according to a **National Water Resource Classification System** (NWRCS or "Classification System") (Dollar *et al.* 2010), to determine the future level of protection and define specific objectives for the resource (Resource Quality Objectives), which is then used to determine the quantity and quality of water to be allocated to the Reserve

Recognising that it will take some time to classify all water resources in the country, provision has been made in the NWA for the determination of a **Preliminary Reserve** and hence an interim framework issuing of water use licences. Methods to determine the Preliminary Reserve were established soon after the promulgation of the NWA and have been in use since then (DWAF 2008).

These methods follow a generic methodology which can be carried out at different levels of effort to produce a determination of the ecologists' Recommended Ecological Category and the associated Ecological Reserve. The methods have been slightly modified in the development and evolution of methods for rivers, estuaries, wetlands and groundwater, but the same process is essentially followed in each. This study follows the latest method for estuaries (Version 3 – DWA 2012). Four of the main authors of the method were on the study team of the Klein assessment. The steps of the method are outlined below.

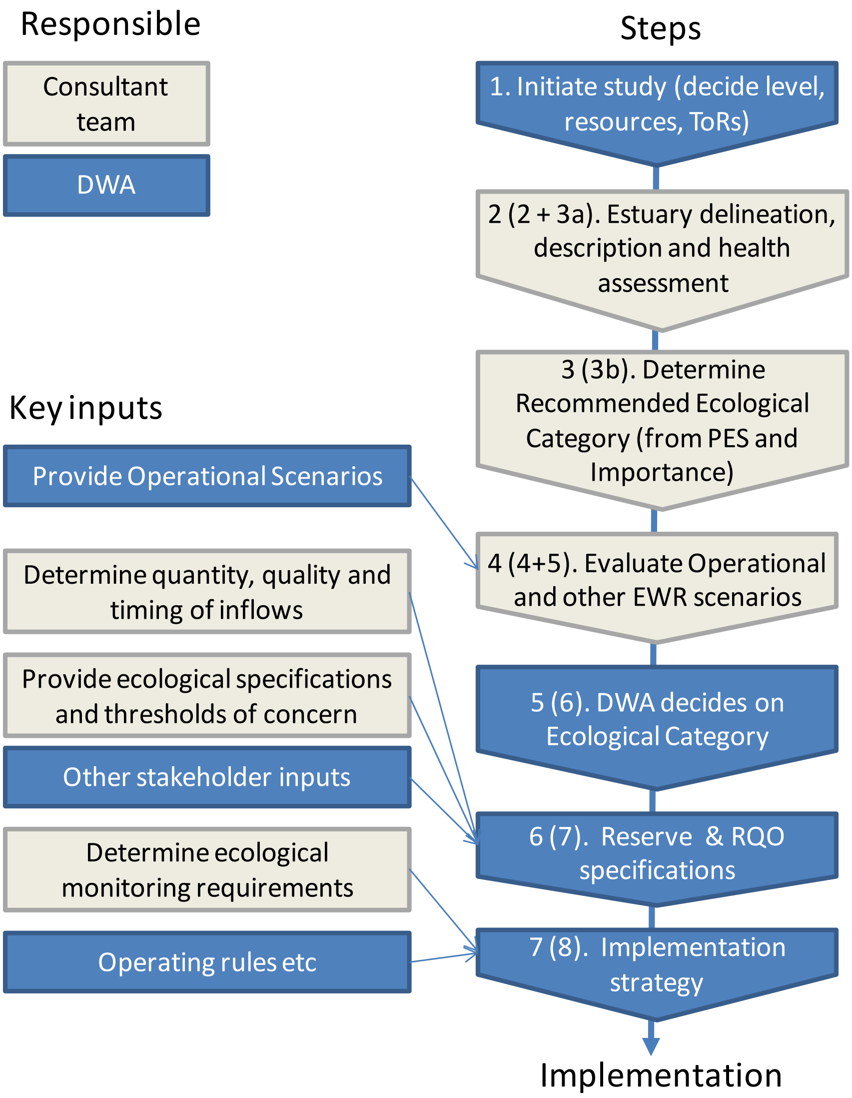


Figure 1.1. **Procedures for determination of the preliminary Reserve for estuaries, giving Version 3 step numbers and former step numbers in parentheses (DWA 2012).**

Step 1: Initiate the study

This entails defining the study area, the study team, and the level of study.

Step 2: Define the resource units.

Delineate the geographical boundaries of the resource by breaking down the catchment into water resource units which are each significantly different from the other to warrant their own specification of the reserve, and clearly delineate the geographic boundaries of each unit.

Step 3: Determine Recommended Ecological Category (i.e. preliminary classification)

This step entails estimating the reference and present condition and ecological importance in order to determine the Recommended Ecological Category. The Reference Condition refers to the natural, unimpacted characteristics of a water resource, and must represent a stable baseline. This usually requires expert judgement in conjunction with local knowledge and historical data. Reference conditions are generally described in terms of:

- water quantity (amount, timing, pattern and levels of flow, including seasonal and inter-annual variability, flood and drought cycles)
- water quality (the concentrations of key water quality constituents, including their seasonal and inter-annual variability, and going as far as diurnal patterns of variability for constituents such as temperature, dissolved oxygen and pH)
- geomorphological and vegetation aspects of habitat. In the case of estuaries, this also includes mouth condition.
- character, composition and distribution of aquatic biota

The Present Ecological Status of resource quality (water quantity, water quality, habitat and biota), is assessed in terms of the degree of similarity to reference conditions. This helps to identify what may be desirable or achievable as a future management class. The assessment is summarised in terms of the classification system of A to F described in Table 1.1.

The Recommended Ecological Category is set as one of the first four ecological categories (A to D) utilized in identifying the present status assessment (Table 1.1). This category is the target for protection and management of the resource. This could be the same as the Present Ecological Status, or could be higher if an improvement in resource condition is desired. It has always been intended that when the full ecological Reserve implementation phase begins (using the Classification Process), the process of assigning the Ecological Class will be a consultative one, aimed at involving stakeholders in deciding the level of resource protection which is required. Criteria for assigning a class to a resource include:

- the sensitivity of the resource to impacts of water use (whether due to ecological sensitivity, or the sensitivity of water users)
- the importance of the resource, in ecological, social, cultural or economic terms
- the value of the resource, in ecological, social, cultural or economic terms
- what can be achieved towards improvement of resource quality, given that not all past impacts may be reversible

Step 4: Quantify Ecological Water Requirements
The reserve is quantified for the recommended category and alternative categories. This is the most technically demanding of the steps; the rules are rigorous procedures for deriving site-specific numerical objectives which are appropriate for the reference conditions of a particular resource.

Step 5: Ecological consequences of operational scenarios
Operational scenarios are evaluated in terms of the predicted future condition of the resource under each scenario.

Step 6: Decide on management category (DWA process)

DWA considers the recommended category in the light of other factors, and makes a decision (A to D).

Step 7: Reserve specification

This entails setting the Resource Quality Objectives (quantitative specifications), and the water quantity and quality parameters of the Reserve. In a Reserve determination study, these are presented as recommendations.

Step 8: Implementation strategy

This entails the strategy for implementation of flows (operating rules in the case of a dam) and other mitigation measures as well as designing a monitoring programme. In a Reserve determination study, these are presented as recommendations.

Table 1.1 The six Ecological Classes for indicating the present ecological status of the resource, as well as selecting the future ecological status (italics). Categories A to D are within the desired range, whereas E and F are not (Kleynhans 1996, MacKay 1999).

EC	Description
A	**Unmodified, or approximates natural condition**; the natural abiotic template should not be modified. The characteristics of the resource should be determined by unmodified natural disturbance regimes. There should be no human induced risks to the abiotic and biotic maintenance of the resource. The supply capacity of the resource will not be used.
B	**Largely natural with few modifications**. A small change in natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged. *Only a small risk of modifying the natural abiotic template and exceeding the resource base should not be allowed. Although the risk to the well-being and survival of especially intolerant biota (depending on the nature of the disturbance) at a very limited number of localities may be slightly higher than expected under natural conditions, the resilience and adaptability of biota must not be compromised. The impact of acute disturbances must be totally mitigated by the presence of sufficient refuge areas.*
C	**Moderately modified**. A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged. *A moderate risk of modifying the abiotic template and exceeding the resource base may be allowed. Risks to the wellbeing and survival of intolerant biota (depending on the nature of the disturbance) may generally be increased with some reduction of resilience and adaptability at a small number of localities. However, the impact of local and acute disturbances must at least partly be mitigated by the presence of sufficient refuge areas.*
D	**Largely modified**. A large loss of natural habitat, biota and basic ecosystem functions has occurred. Large risk of modifying the abiotic template and exceeding the resource base may be allowed. Risk to the well-being and survival of intolerant biota depending on (the nature of the disturbance) may be allowed to generally increase substantially with resulting low abundances and frequency of occurrence, and a reduction of resilience and adaptability at a large number of localities. However, the associated increase in the abundance of tolerant species must not be allowed to assume pest proportions. The impact of local and acute disturbances must at least to some extent be mitigated by refuge areas.
E	**Seriously modified**. The loss of natural habitat, biota and basic ecosystem functions is extensive
F	**Critically modified**. Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible

1.2 Definition of confidence levels

The level of available historical data in combination with the level of effort expended during the assessment determines the level of confidence of the study. Three levels of study have been recognised in the past in terms of the effort expended during the assessment – rapid, intermediate and comprehensive. In this study, effort lay somewhere between a rapid and intermediate study, in that some field data collection was carried out, but overall would be classed as a 'Rapid' study. Nevertheless, the paucity of historical data on the system meant that we expected the confidence of the study to be low. This is a situation that can only be remedied with some comprehensive and long term data collection on the system. Criteria for the confidence limits attached to statements in this study are shown in Table 1.2.

Table 1.2. Confidence levels for an Estuarine EWR study

Confidence level	Situation	Expressed as percentage
Very Low	No data available for the estuary or similar estuaries	(i.e. < 40% certain)
Low	Limited data available	40 - 60% certainty
Medium	Reasonable data available	60 – 80% certainty
High	Good data available	> 80% certainty

1.3 Specialist team

The following specialists were on the study team:

Specialist	Affiliation	Area of responsibility
Dr Barry Clark	Anchor Environmental Consultants	Study leader
Stephen Mallory	Institute for Water Research	Hydrology
Ms Lara van Niekerk	CSIR	Physical processes, hydrodynamics & editing
Dr Susan Taljaard	CSIR	Water quality
Prof Janine Adams	Nelson Mandela Metropolitan University	Microalgae and macrophytes
Mr Aiden Biccard	Anchor Environmental Consultants	Invertebrates
Dr Stephen Lamberth	Independent	Fish
Dr Jane Turpie	Anchor Environmental Consultants	Birds & overall method & editing
Ms Katherine Forsythe	Anchor Environmental Consultants	Birds

1.4 Assumptions and limitations for this study

The following assumptions and limitations should be taken into account:

- Only limited new data were collected on invertebrates and birds as part of this study a one-day field visit to the estuary in March 2015. All assumptions made as part of this assessment are thus mostly based on historical data and expert opinion.
- The hydrology of the catchment was modelled using the Water Resource Modelling Platform (Mallory, Desai and Odendaal, 2011) using WR2005 zonal rainfall data
- The overall confidence in the hydrological data provided to the estuarine team by the IWR Water Resources was Low.
- The accuracy of the predicted abiotic states for the Klein Estuary and the distribution of these states under the reference condition, present state and future flow scenarios depend largely on the accuracy of the simulated runoff data and measured data. Confidence was thus Medium to Low.
- The water balance model was calculated on the present breaching level (+2.6 m MSL).

1.5 Structure of this report

The report is structured as follows:

Chapter 1	provides an overview of the process, the level of effort and confidence of the study and study team.
Chapter 2	defines the geographical boundaries of the study area;
Chapter 3	provides a baseline description and health assessment of the estuary. This chapter starts by introducing the context of the estuary, then describes each of the abiotic and biotic aspects of the estuary, from hydrology to birds. For each of these components, our understanding of the present situation is described, the reference situation is estimated, and then the present state is scored in terms of its similarity to the estimated reference state. The overall state of health is then computed using the Estuary Health Index.
Chapter 4	combines the EHI score with the Importance score for the system to determine the Recommended Ecological Category. It also summarises the overall confidence of the study and the degree to which non-flow factors have contributed to the degradation of the system.
Chapter 5	describes six alternative future scenarios, and determines the Ecological Category for each of these.
Chapter 6	provides the recommendations regarding the flow requirements for the system, the ecological specifications that must be met, and recommendations for a monitoring programme. It also discusses the way forward for management of the estuary mouth.
References	lists all references cited in this report.
Appendix A	provides a summary of the data that were available and/or collected for the study.

2 LOCATION AND DELINEATION OF THE KLEIN ESTUARY

The Klein Estuary is situated more or less midway between Cape Point and Cape Agulhas on the south-west coast within the cool temperate biogeographic region of South Africa. It enters the sea at 34°24'58"S 19°17'35"E (Whitfield 2000). The geographical boundaries for the study are defined as follows:

Downstream boundary:	Estuary mouth 34°24'58"S 19°17'35"E
Upstream boundary:	34°25'53"S, 19°27'30"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

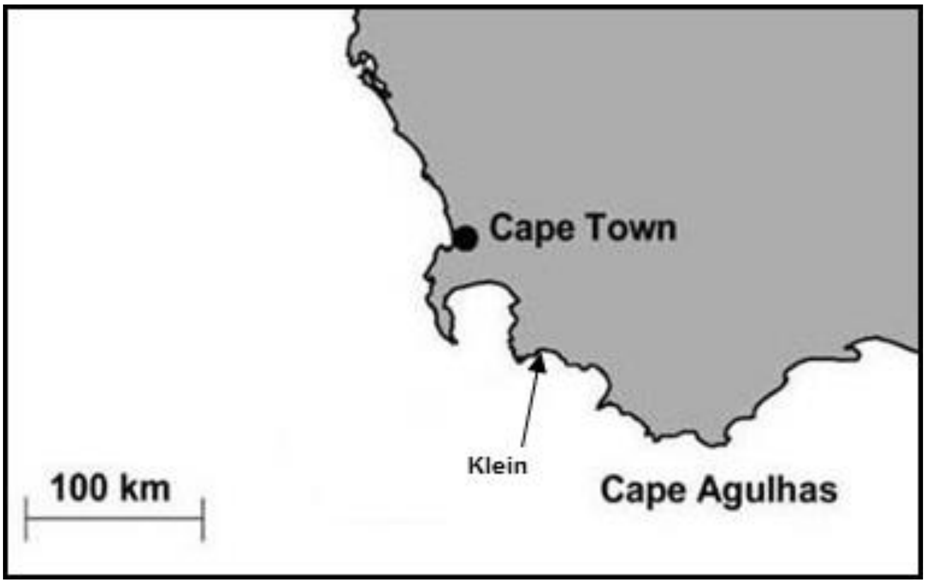


Figure 2.1. Map of the south western tip of South Africa, showing the position of the Klein Estuary

Figure 2.2. Geographical boundaries of the Klein Estuary.

3 BASELINE DESCRIPTION AND HEALTH ASSESSMENT

3.1 Overall context and pressures

3.1.1 Catchment description

The Klein River catchment is situated in the south west of the Breede-Overberg Water Management Area in the Western Cape Province. The main inland urban area in the study area is the town of Stanford and the coastal town of Hermanus. According to the description provided in the Breede WMA Internal Strategic Perspective (ISP) (DWAF 2004), the Klein River and its main tributaries, the Hartebees, Steenbok and Karringsmelk rivers initially flow through well-developed agricultural land (G40J and G40K quaternary catchments), which consists mainly of dryland agriculture with some commercial irrigation in the form of centre pivots. The bulk of the irrigation occurs in the G40J catchment. The G40L catchment agriculture practices consist of dryland agriculture and vineyards. The river then flows into the Klein River Lagoon (G40L). Refer to Figure 3.1 and Figure 3.2 on which the three quaternary catchments making up the Klein River catchment are delimited.

The total quaternary catchment area according to WR2005 (Middleton and Bailey, 2005) is 983 km^2 (Table 3.1). The catchment was digitized using PlanetGIS as part of this study using 20 m contours and the total catchment area contributing to the Klein River estimated at approximately 819.16 km^2. Note that this estimate excludes the small coastal rivers towards the south East of the catchment that are not contributing to the runoff into the Klein River.

Table 3.1. Catchment areas.

Quaternary Catchment	WR2005 (km^2)
G40J	169
G40K	429
G40L	385
TOTAL	**983**

Figure 3.1. Klein River Quaternary catchments.

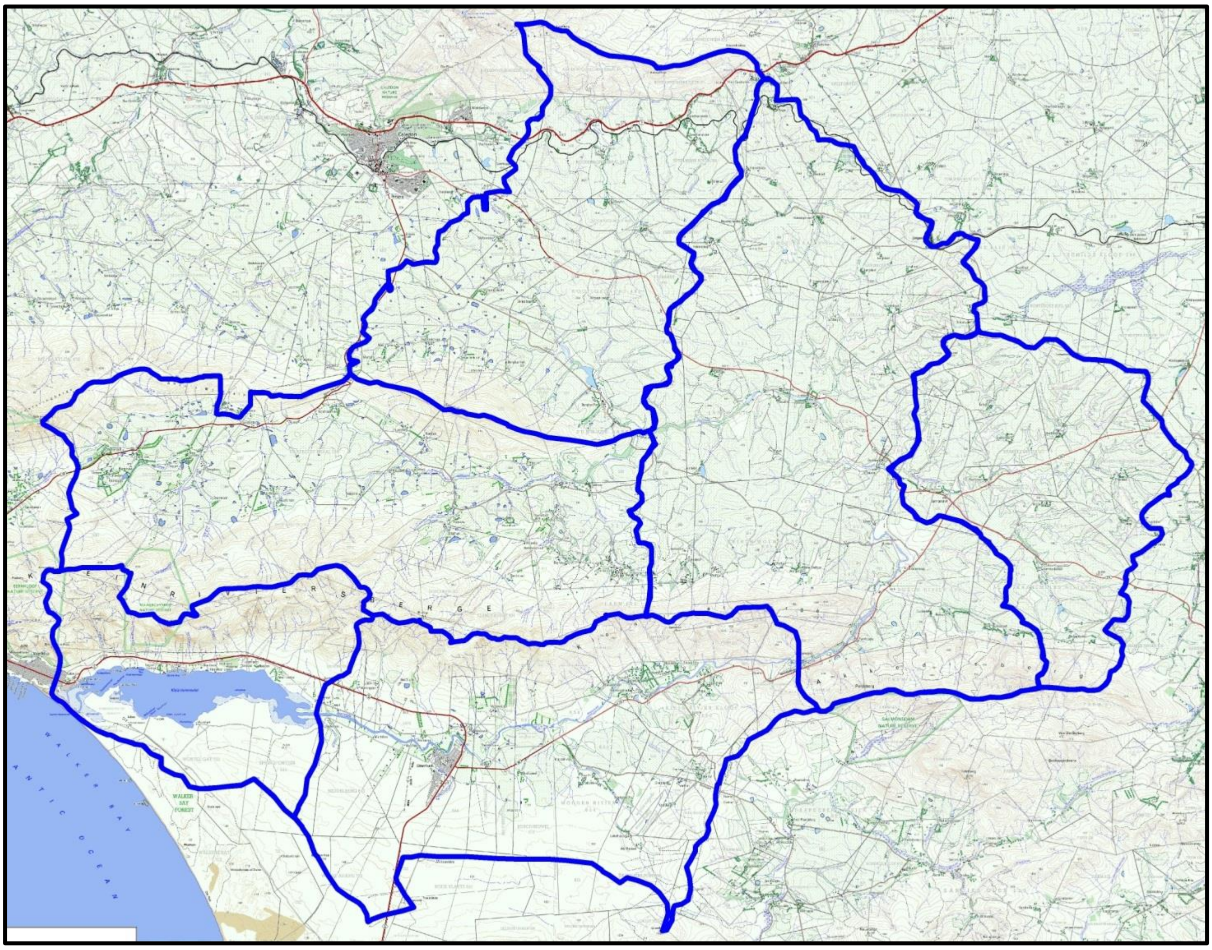


Figure 3.2. Klein River sub-catchments

3.1.2 Catchment population

Whitehead *et al*. (2007) presents information about the demography of the Overstrand area obtained from the ODM Annual Report (2006/7) and the Overstrand IDP. Since 2001, population growth rate in the Overstrand has been higher than the district average with a forecast population for 2010 of 130,353. The town of Hermanus is considered to have high development potential (DEA&DP 2005) due mainly to economic change, commercial services and regional vitality. Tourism and recreation are considered the economic base of the town but growth is threatened by limiting availability of fresh water, inadequate access roads and limited scope for the lateral expansion of the town.

3.1.3 Land use

According to the land use map below (Figure 3.3), commercial irrigation is predominantly located in the upper catchments on the Hartbees River and the Steenbok River tributary in the G40J and G40K quaternary catchments and in the south along the Klein River within the G40L quaternary catchment. Most of the agriculture in the Klein River catchment is dryland, and the most predominant land use of the G40J, G40k and G40L quaternary catchments.

Whitehead *et al*. (2007) offer the following comments on the state of the Klein catchment and estuary:

- The density of development around the estuary is generally low, with the exception of the nodal urban areas of Hermanus and Stanford and some resorts.
- Existing development around the estuary is visually relatively unobtrusive from the vantage point of public roads in the area, including the R43 proposed scenic route.
- Existing land use zoning is (assumed to be) predominantly agriculture;
- 17% of the sub-catchment G40L is included in designated protected areas (public and private)
- There are two intensive feed farming agricultural sites located within approximately 700 metres of the river on the east bank near Stanford. Intensive feed farming potentially generates negative environmental impacts and requires regular monitoring.

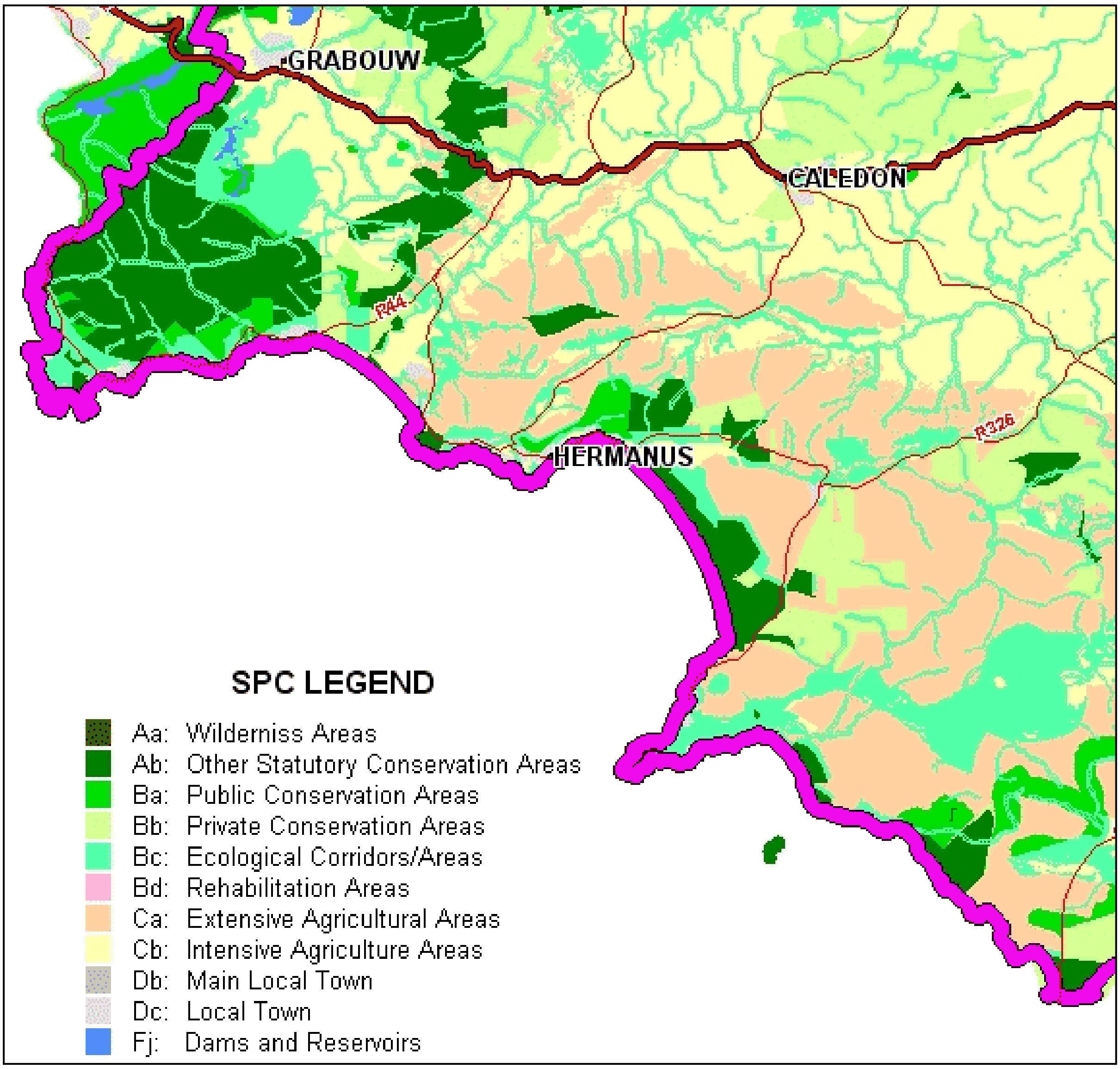


Figure 3.3. Land use in the Klein River catchment.

3.1.4 Human influences affecting the estuary

3.1.4.1 Flow-related influences

Water abstraction from the catchment is decribed in Section 3.2.2 below but is summarised in Table 3.2 below.

Table 3.2. Activities affecting the quality and quantity of flows into the estuary

Activity	Extent of problem
Water use for irrigation	Extensive agricultural activities in the catchment
Agricultural and pastoral run-off containing fertilisers, pesticides and herbicides	Extensive agricultural activities in the catchment have increased inorganic nutrient loading in river inflow and most likely levels of pesticides and herbicides.
Stanford WWTW	Increased inorganic nutrient loading in river inflow
Septic and conservancy tank seepage	The contribution to nutrient loading from septic and conservancy tank seepage is considered to be low
Litter	The amount of litter in the estuary derived from the catchment is low owing to low levels of development in the catchment.

3.1.4.2 Non flow-related influences

The Klein estuary is used extensively for recreational purposes, and is reported to have high local, regional and even international value (Whitehead *et al.* 2007). It is a popular venue for sailing, canoeing, kite surfing. Other activities in and around the estuary include hiking, horse riding, birding, swimming, fishing, boating (motor and oars), water-skiing, jetskiing (permit only), and windsurfing. Commercial users within the defined estuarine functional zone include only riverboat cruises that operate from Stanford. These include the privately operated Platanna River Cruises and the African Queen (Whitehead *et al.* 2007). In the area surrounding the estuary, commercial enterprises include those based on tourism, agriculture and agri-business such as overnight accommodation (lodges, B&Bs and self-catering facilities), horse trails, vineyards and a large County Fair chicken farm.

Poaching of marine organisms in the Overstrand area, particularly the use of illegal gill nets to trap fish in the Klein and Bot River estuaries, has received a lot of media attention in recent decades. Some effort has been made to control poaching but anecdotal evidence suggests that this has met with little success. Other forms of illegal exploitation includes lack of fishing or bait collection permits, exceeding of bag limits for fish and bait and illegal gill netting of fish (Whitehead *et al.* 2007).

Other activities that have been highlighted as being of concern on the Klein estuary includes the lack of permitting of watercraft; motorboat users not adhering to promulgated use zones, speed regulations and regulated times of use; dumping and leaching of sewage from inadequate, badly located or neglected septic tanks, littering; pollution through runoff (fertilisers, pesticides, swimming pool backwash); occupation of boathouses for overnighting purposes; erection of any structures below the 1:50 year floodline and/or the high water mark, in particular the erection of jetties by riparian landowners, without the necessary authorisation

Table 3.3. Land-use and development related activities affecting the abiotic characteristics in the estuary

Activity	Describe impact
Municipal waste (including sewage disposal)/infrastructure problems	The Stanford WWTW is an important source of organic matter and inorganic nutrients to the Klein estuary but provides a lower contribution than that from agricultural activities the catchment.
Bridge(s)	Stanford bridge at the top just after the head of the estuary
Artificial breaching	Artificial breaching has been practise at the Klein Estuary for more than a century.
Low-lying developments	Significant number of low-lying properties along the length of the system. Also problem with access routes that get inundated.
Bank stabilisation/erosion	Some riparian vegetation has been removed by grain farmers to prevent roosting and nesting of seed eating birds. This has resulted in localised destruction and bank erosion.

Table 3.4. Summary of living resources utilisation in the Klein estuary

Activity	Present	Describe impact
Recreational fishing	Yes	Recreational fishing (shore and boat angling) are both popular on the Klein estuary and are considered to be having a moderate impact on stocks of exploited species in the estuary.
Illegal fishing (Poaching)	Yes	Illegal net fishing is a huge problem on the Klein estuary and is having a very significant impact on linefish species such as kob, leervis and white Steenbras in the estuary.
Bait collection	Yes	Bait collecting (sand prawns, mud prawns, bloodworm and pencil bait) is a popular pastime on the Klein estuary and are having a significant impact on stocks of exploited species in the estuary, particularly bloodworm and sand prawns.
Grazing and trampling of salt mashes	Yes	Limited impact
Translocated or alien fauna and flora	Yes	There are at least six alien fish species in the Klein estuary including Mozambique and banded tilapia and three species of bass (smallmouth, large mouth and spotted bass). These fish compete with (tilapia) and predate on (bass) indigenous fish species that use the estuary and are affecting populations of the latter species.
Recreational disturbance of waterbirds	Yes	Kite surfing and sailing are both very popular past-times on the Klein estuary and are almost certainly having negative impacts on water birds (waders, wading birds and waterfowl) on the estuary.

3.2 Hydrology

3.2.1 Water resources infrastructure/information

There are also no major dams within the Klein catchment, however, there are numerous farm dams that are used to supply water for irrigation. The largest registered dam is Tolbos Dam with a capacity of 238 million m^3. Some of the larger farm dams in the catchment are listed in Table 3.5. Many of dams appear to be used as off-channel storage.

Table 3.5. Dams located in the quaternary catchments of the Klein River.

Name of Dam	Quaternary catchment	Capacity (million m^3)	Use
Eerstehoop-Wit	G40J	82	Irrigation
Eliasgatdam	G40J	136	Irrigation
Smaldam	G40J	151	Irrigation
Tolbosdam	G40J	238	Irrigation
Appelsdriftdam	G40K	160	Irrigation
Goodluckdam	G40L	110	Irrigation

3.2.2 Water use

To obtain up-to-date water use information, Water Authorisation and Registration Management System (WARMS) data was obtained from the Department of Water and Sanitation (DWS). On inspection, much of the information was found to be erroneous. Most of the errors in the data are related to the fact that water use or the sources of the water are not within the quaternary catchment in which they are registered. This includes the dams that have been registered on rivers which do occur in the quaternary catchments of the Klein River.

3.2.2.1 Irrigation

Registered water use for irrigated agriculture sourced from the DWS WARMS database, after removing registered use which is clearly not located in the catchment, is shown in Table 3.6. Irrigated areas in each of the quaternary catchments according to the WR2005 database are listed in the same table.

Table 3.6 Table of registered abstraction in the study area from WARMS and irrigated areas according to WR2005.

Quaternary Catchment	Irrigation volume (Million m^3/a)	Irrigation area (km^2)
G40J	4.13	6.92
G40K	2.23	3.18
G40L	2.33	2.00

3.2.2.2 Domestic/Urban and industrial

According to the Water Services Development Plan (WSDP) the town of Stanford obtains its entire potable water requirement from springs. Thus total industrial and domestic supply from surface water sources within the catchment is estimated at only 0.444 million m^3/a.

3.2.2.3 Forestry

There is no documented forestry within the Klein River catchment. However, there is extensive alien invasive vegetation documented for the Klein River catchment. According to the Breede WMA ISP report (DWAF 2004), the impact of invasive alien plants in the Overberg (within which the Klein River catchment is) is extreme. The areas of alien vegetation were obtained from the Kotze (2010, Table 3.7).

Table 3.7 Area of Alien Invasives from WR2005

Quaternary catchment	WR2005 Extent of alien invasive plant (km^2)
G40J	19.5
G40K	5.26
G40L	65.5

Owing to the large amount of infestation of the riparian zone of the rivers in the Klein River catchment and the effect on the water resources, it was decided to include this in the modelling. Kotze (2010) indicates that alien infestations of the lower reaches and river courses are mainly of the Acacia species. For the modelling purposes, it was therefore decided to add the area of alien invasives reflected in Table 3.7 above.

3.2.3 Natural and Present day flows

In order to understand the ecological water requirements of the estuary and determining the natural and present day simulated freshwater flow sequences, the Water Resource Modelling Platform (Mallory, Desai and Odendaal, 2011) was used. The natural flow sourced for WR2005 was based on the calibration of the WRSM2000 model against the observed flow in the Klein River at the G4H006 gauge. The upper catchments (G40J and G40K) of the Klein River are in the G4A rainfall zone and the lower catchment (G40L) is in the G5B rainfall zone.

Table 3.8 Hydrological information captured from WR2005

Quaternary catchment	Natural Mean Annual Runoff (MAR) (million m^3/a)	Mean Annual Precipitation (MAP) (mm/annum)	Mean Annual Evaporation (MAE) mm/annum
G40J	19.2	702	1440
G40K	25.0	576	1430
G40L	23.9	590	1440
Total	**68.1**		

The WR2005 natural MAR for the Klein River catchment is estimated at 68.1 million m^3/a, compared to the natural MAR provided by WR90 of 45.1 million m^3/a. As indicated in Figure 3.1 and Figure 3.2, not all the runoff from the G40L catchment flows into the estuary. It is estimated that 58% of the runoff from G40L flows into the estuary. Hence the Natural MAR for the estuary is 53.41 million m^3/a. The Present Day MAR for the estuary, after abstractions for irrigation and domestic and industrial use and that taken up by AIPs has been accounted for, is thus 40.88 Mm^3/a or 77% of Natural.

Time series data for Present day and Reference flows are shown in Figure 3.4 and Figure 3.5, respectively. Monthly flow data are included as Appendix 1 and 2.

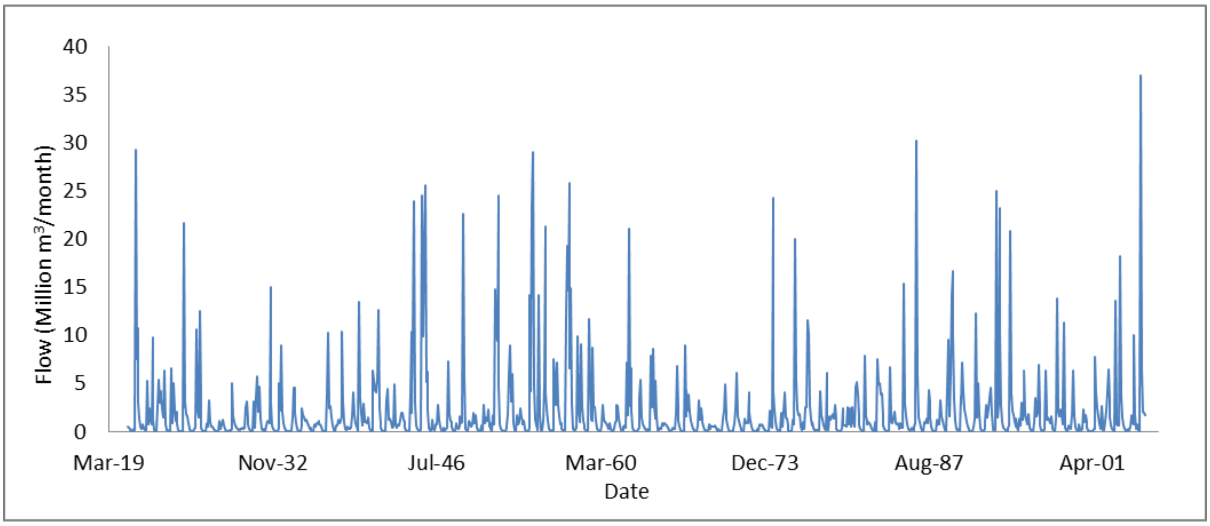


Figure 3.4. Times series flow data for the Klein estuary under Reference conditions.

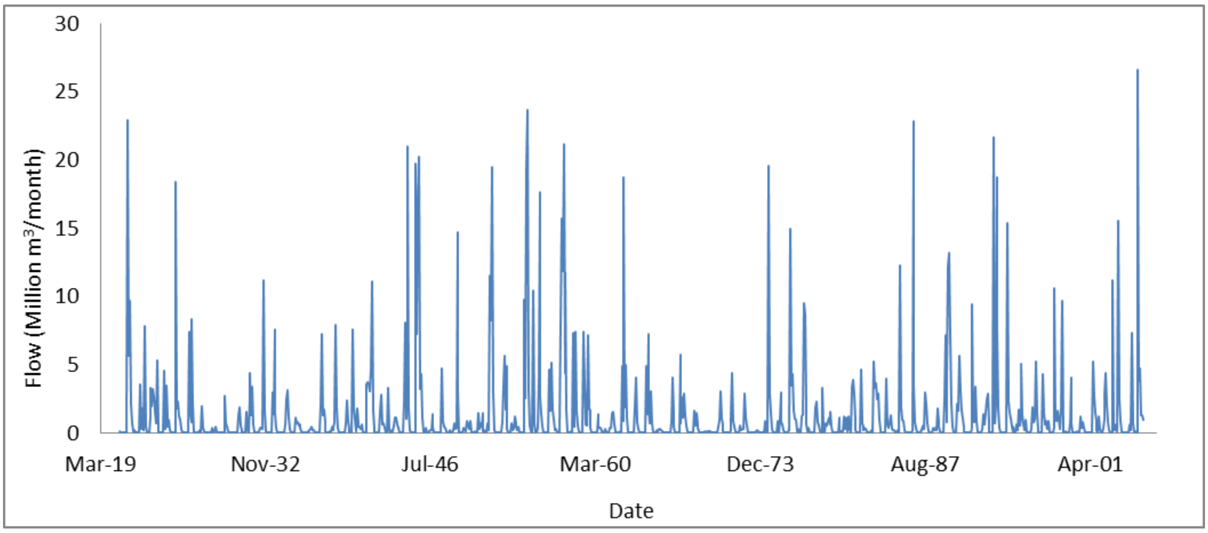


Figure 3.5. Times series flow data for the Klein estuary under Present day conditions.

3.2.4 Present hydrological health

The present day flood regime for the Klein River is judged to be very similar to Natural as the dams in the catchment are relatively small. From the simulated runoff data, it is estimated that flood frequency is at least 87% similar to Reference conditions. Total Present Day MAR has decreased more significantly than this (estimated at 77% of Natural) and this is clearly manifest in the increased occurrence of low and zero flow condition. Under Reference conditions there were no months between 1920 and 2004 when zero flow was registered. However, under Present day conditions, zero flows were registered 30% of the time. Average monthly flow in the months when flow is lowest (Dec-Mar) under Present Day conditions is 50% of that under Reference conditions.

As an estuarine lake system, the Klein estuary is sensitive to any change in inflows. Thus, hydrological health was assessed on the basis of the overall change in MAR between Reference and Present only (i.e. did not take account of the change in flood frequency), and was allocated a score of 77% (Table 3.9).

Table 3.9. Calculation of the hydrological health score, giving examples in italics

Variable	Score	Motivation	Conf
1. % Similarity in present MAR as a % of MAR in the Reference condition	77	The reference MAR have been reduced from 53 to 41 x 10^6 m^3	M
2. Change in flood frequency	87	Present day flood regime very similar to Reference as dams in the catchment are relatively small	L
Hydrology score	77		M

3.3 Physical habitats

3.3.1 Klein Estuary zonation

Figure 3.6 shows the zonation for the Klein Estuary.

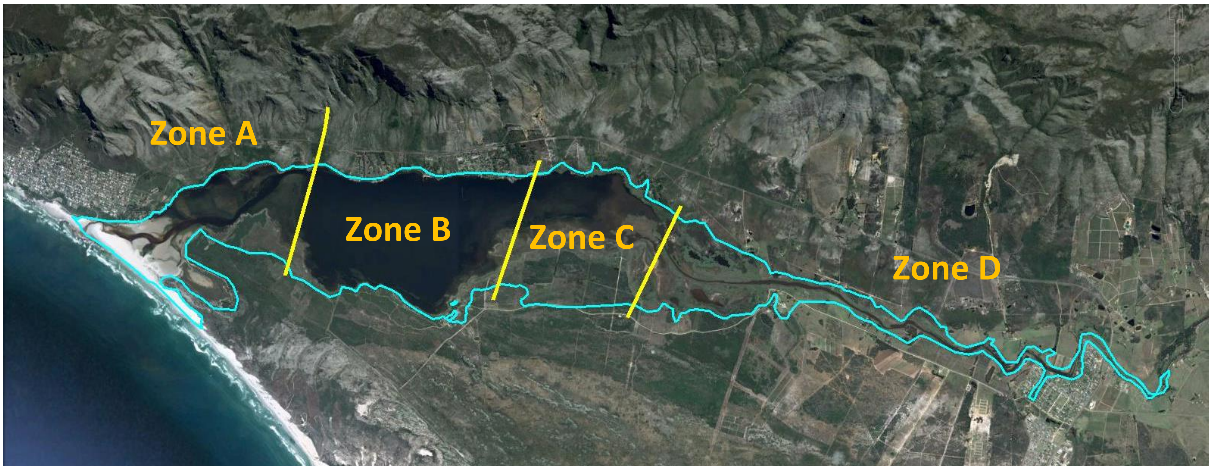


Figure 3.6. Zonation of Klein Estuary.

The following key features were taken into consideration during the zonation process:

Table 3.10. Key physical features taken into consideration during the estuary zonation process

	Zone A	Zone A	Zone A	Zone A
Area (ha) under closed conditions	295	542	247	70
Depth (m) when open	0.5-1.0 (Mostly dry when open)	2.0-3.0	0.5-1.0 (Very shallow to dry when open)	2.0-3.0

3.3.2 Available information on bathymetry and sediments

The Klein Estuary is bounded to the north by the Kleinriviersberge composed of Table Mountain Group, while its southern shore is composed of coastal limestone (calcretes). Fringing the southern shore of the estuary, are lithified dunes covered by a calcrete cap. These calcretes are replaced on the seaward side by modern sand dunes. These dunes progress in a general west to east direction and form dunes up to 30 m high, at intervals of 300 to 500 m. Stablisation of the dunes with *Acacia cyclops* (Rooikrantz) and indigenous dune vegetation during the 1940s has prevented any further movement of the dunes in modern times. A vegetated dune has been artificially created Intermediately to the east of the estuary mouth that affects the mouth dynamics of the system.

A number of alluvial fan deltas occur along the northern shore, where rivers discharge their load from the mountains into the estuary. The largest of these deltas is formed by the Voëlgat River, which enters the estuary west of Kettle Point. The alluvial fan deltas introduce poorly sorted sediments along the northern margin of the system, with coarse sands and gravels deposited nearshore and fines deeper into the estuary. For example, on 11 May 2005 a cut-off low caused severe flooding and erosion of the mountain slopes. Deposition of poorly sorted material at the time resulted in significant localised infilling around the Voëlgat Fluvial fan.

Figure 3.7. Sediment deposition Voëlgat River into Klein Estuary, 11 May 2005 (Source: Mr Ed Lucas)

A talus slope occurs along the northern shore of the Klein River, derived from mechanical and chemical weathering of the Kleinriviersberge. Nearer the lagoon, rock fragments have been rounded by wave action and form boulder-strewn beaches.

The sediments in the Klein Estuary are derived from three main sources: the river, the sea and bank erosion. The sediment to the east of Maanskynbaai consists mainly of sand, silt and clay fractions, with minor horizons of gravel. In the main water body, sediments consist mostly of fine sand fractions that dominate in the lower reaches and shores of the system. On the northern shores, sediments are coarser, becoming finer grained with increasing depth. On the southern shores, however, the nearshore sediments are finer than those in the slightly deeper water (1.0-1.5 m), where after they become finer with increasing depth. Fining occurs during sediment reworking by wave action (ocean and wind generated) along the shore and transport into deeper waters.

The sediments of the flood delta area are dominated by the fine sand fraction. Very fine sediments are also found in the channels traversing this area. When water levels are low, wind may winnow fine sands from exposed areas, leaving a medium sand fraction behind. Very limited amounts of gravel occur in the system, and is mostly associated with deltas or shallow areas were strong wave action has removed finer material.

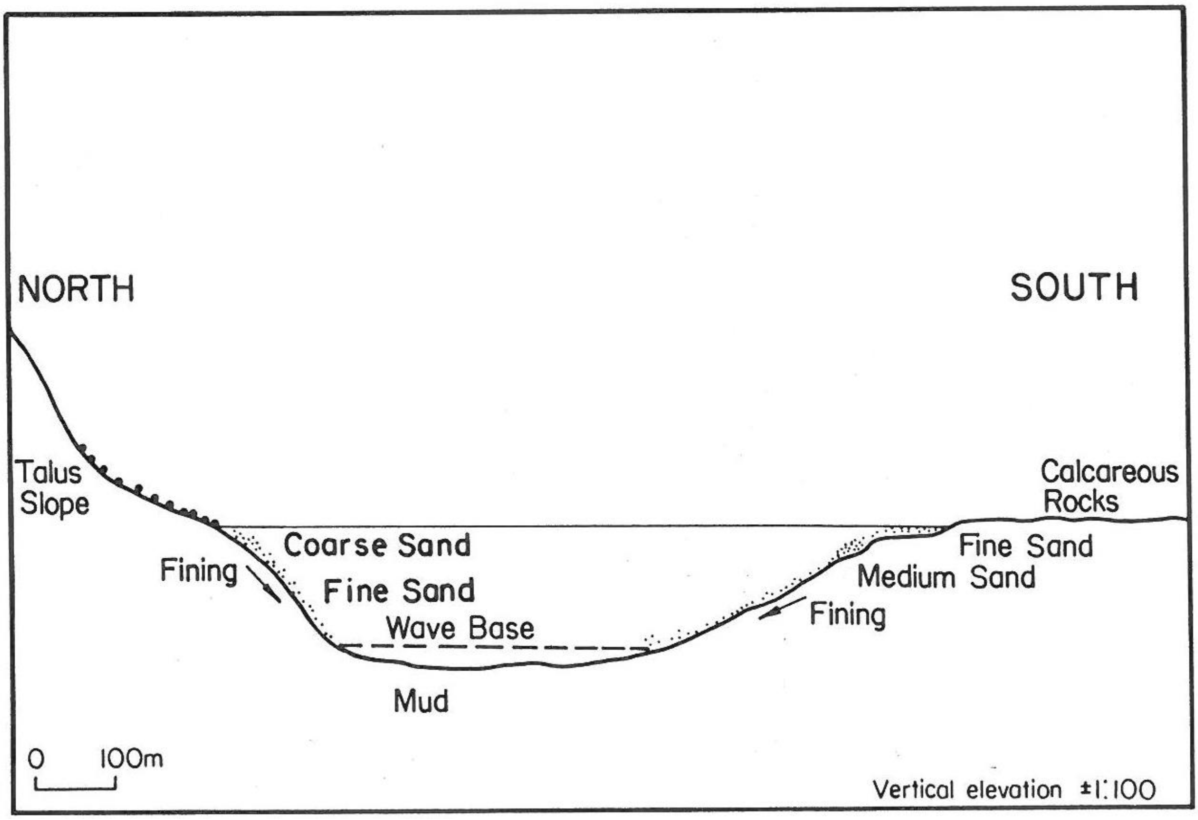


Figure 3.8. Cross-section of the sediment distribution in relation to bathymetry (CSIR 1989)

3.3.3 Physical habitat health

Historically, the Klein River delivered a relatively low sediment load into the estuary, most of which was fine sediment. The significant agricultural activities in the catchment have, however, led to increased land erosion and thus sediment yield to the estuary. Anecdotal accounts suggest that there may be some progressive sedimentation in the upper reaches of the estuary (Zone C). These sediments would be of fluvial origin.

While floods generally play a significant role in scouring sediments from estuaries, in the case of the Klein, the effect is somewhat moderated due to the large surface area of the system that attenuates floods in the main water body. Thus, the scouring impact of floods is mostly confined to the upper reaches (Zone D) and the lower reaches (Zone A), with Zone B and C acting as sediment dispositional areas.

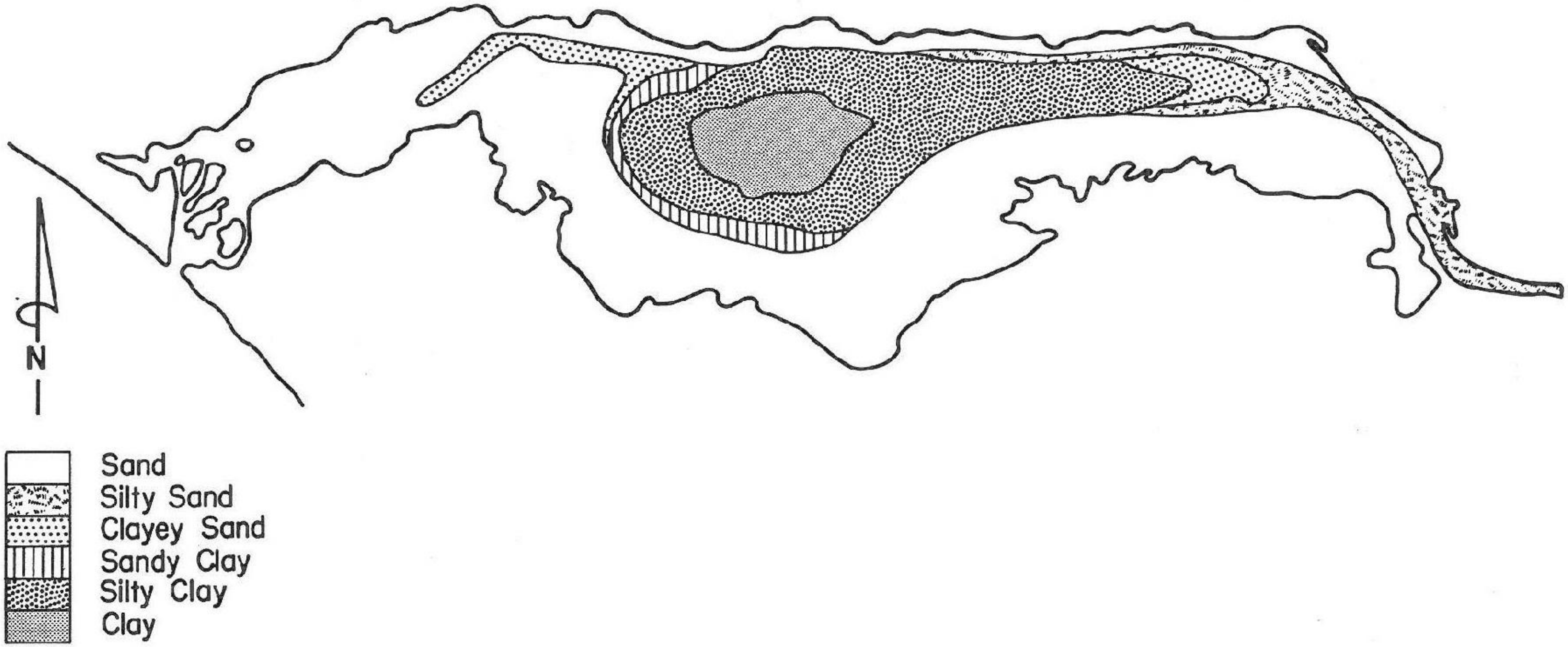


Figure 3.9. Distribution of the sediments in the Klein Estuary. Source: De Decker (1989).

Besides river flow, the main hydraulic driver in the estuary is the ocean tide. As a more than ample supply of marine sediment is present at the Klein Estuary mouth for potential transport into the estuary, this is a major source of sediments to the system. Thus, the amount of marine sediment intrusion into the estuary is mainly dependent on the (nett) transport capacity of the ebb and flood tidal flows near the mouth, and not on the amount of sediment available outside of the mouth. During neap tides, maximum velocities are low with very little transport, while both velocities and transport increase towards spring tides. During low river flow periods, the net sediment transport in the estuary relies on a subtle balance between dominant flood and ebb tide flows. More sediment enters the mouth on the flood tide than can leave on the ebb.

Mouth breaching and floods are the only mechanisms for removing sediment from the system, with the near annual mouth breaching being the more important factor in maintaining the equilibrium in the lower reaches of the system.

Pertinent impacts on physical drivers and morphologic and sediment dynamics characteristics include:

- Reduction in floods as a result of water abstraction from the catchment,
- Increased sediment input from the river catchment,
- Clearing of riparian vegetation, riparian development, agricultural livestock grazing and trampling,
- Road, riparian and instream infrastructure, and
- Alien vegetation in the supra-tidal zone.

3.3.4 Physical habitat health

Estuarine sediment processes operate at different scales from hydrodynamic, biogeochemical and biological processes. Accretion and erosion of subtidal areas (also reflected as changes in volume) can occur at daily to monthly time scales, whereas intertidal areas may vary over seasonal to decadal time scales.

Supratidal process cycles tend to be at even longer time scales as they require major events to reset or reconfigure these areas, typically linked to 1:20 year or larger events. Coastal development also tends have different impacts on the different habitat types and therefore needs to be assessed separately.

To provide context to present ecological health of an estuary, and future trajectories of change, the physical habitat of an estuary is disaggregated into is four principal physical habitat types and described below in Table 4.8 below.

Table 3.11 Present physical habitat scores, as well as an estimate of the change associated with non-flow related factors and an adjusted score only reflecting flow related.

Variable		Summary Of Change	Score	Conf.
a	% similarity in supratidal area	Overall the supratidal geophysical habitat areas in all zones of the estuary (upper, middle, lower & riverine) have been moderately transformed from reference condition in terms of sediment & morphologic characteristics, and have been significantly changed in all zones, mainly by anthropogenic actions and developments, e.g. low-lying developments, road infrastructure encroaches on both banks, alien vegetation on the coastal dunes and berm causing localised infilling. Saltmarshes and natural riparian vegetation in the system have been, and continue to be, degraded or replaced by low-lying developments and infrastructure. These developments encroach directly on parts of the supra-tidal habitat along the estuary margin and also reduce the mitigating effect that natural vegetation provides against erosion due to wave action (caused by wind action and boating) and flood scouring.	65	L/M
b	% similarity in area of intertidal sand- and mudflats	Intertidal geophysical habitat in all zones of the estuary is mostly similar to Reference conditions in terms of sediment & morphologic characteristics, but all zones are subjected to anthropogenic actions and developments. Significant agricultural activities in the catchment have led to increased erosion and thus sediment yield (especially fines) to the estuary. Decreased floods (~ -5%) are likely to result in slightly increased fluvial sedimentation in the riverine and upper reaches of the estuary. Artificial breaching is likely to have contributed significantly to marine sediment ingress into the lower estuary. The small dams will preferentially trap a larger proportion of the coarser sediments, but have very low sediment trapping efficiency and capacity. Instream infrastructure (e.g. jetties and slipways) interfere with the natural hydro & sediment-dynamics of the estuary and sometimes cause localised bank erosion.	80	L/M
c	% similarity in area of subtidal/ submerged sand and mud substrates	Overall the subtidal geophysical habitat areas in zones B and D of the estuary (middle & riverine areas) are still similar to Reference conditions in terms of sediment and morphologic characteristics, but Zone A and C have been significantly changed. The latter two zones have been infilled and deeper water areas are now mostly confined to channel areas at present.	85	L/M
d	% similarity in bathymetry (indirectly estuary water volume)	Overall the bathymetry in zones B and D is probably still relatively similar to reference condition, but Zone A and C have been somewhat reduced, mainly by artificial breaching, flow reduction, catchment developments.	85	L
Physical habitat score (min a to d)			**65**	**L**
% of impact due to non-flow factors			90	
Adjusted score			97	L

3.4 Hydrodynamic functioning and abiotic states

Changes in river inflow and artificial breaching have resulted in major changes in the mouth condition, water level, water column structure (stratification), salinity distribution, and water quality in the Klein estuary. These effects are described in more detail below.

3.4.1 Mouth condition and artificial breaching

During the early 1900s people started settling along the banks of Klein Estuary. To prevent these properties from being flooded, the practice of artificially breaching the mouth of the estuary was instituted (Figure 3.10). Initially, artificial breaching was undertaken by teams of workers using spades. Later, mechanical equipment such as bulldozers became available, enabling artificial breaching at even lower levels (De Decker 1989).

Before human development took place, i.e. under natural conditions, breaching of the Klein Estuary would only occur when the water level inside the estuary exceeded the height of the sand berm at the mouth. During the closed phase, the berm could have built up to levels exceeding 3 m above mean sea level ("MSL") (see CSIR survey data for 1992 and 1994 where the sand berm near mouth had a crest level of 3.0 to 3.5 m MSL - Figure 3.11 and Figure 3.12).

Figure 3.10. Past and present low lying developments that pressurise local auathorities to artificially breach the estuary at lower than natural levels.

When an estuary mouth is closed, the inflow from a river gradually fills the estuary, provided the river inflow exceeds losses due to evaporation and seepage. Under natural conditions, i.e. before human developments took place, the water levels in the estuary would eventually exceed the height of the berm and a breaching would occur at levels often exceeding 3.0 to 3.5 m MSL.

Initially the outflow of water from the estuary into the sea would be through a shallow channel, but with a gradual increase in water levels, on-going scouring of the outflow channel occurs, and eventually a very strong outflow would have created a deep and wide channel between the estuary and the sea. The establishment of the natural outflow channel can take up to half a day or more to establish depending on the inflow.

When breaching occurred at natural levels (up to metre higher than at present) a much larger volume of water would have flowed out to sea over a much longer period, which in turn, would have removed significantly larger volumes of sediments from the middle and lower reaches of the estuary. During a breaching event, the maximum water level in an estuary is reached when the outflow through the mouth exceeds the river inflow. Under moderate to high river inflow conditions, this occurs a few hours after the actual breaching of the sand berm.

CSIR (1999) showed that for the Klein Estuary, the maximum outflow reached under high breaching levels (e.g. 2.63 m MSL) are equivalent to that of a 1:50 year flood. Large amounts of sediments are scoured from the lower estuary and vlei during such events. Under natural conditions, breaching events of this nature and concomitant significant scouring of sediment would have occurred nearly every year. Over time a long-term equilibrium is reached between the flushing of sediments during breaching and the deposition of sediment by tides and wave action under open conditions, which would have prevented the estuary from silting up.

The main difference between an artificial and natural breaching event is that in the case of artificial breaching, a channel is excavated which allow outflow to begin at a lower water level than would naturally be the case. During artificial breaching, an outflow channel is excavated through the berm at a pre-determined water level. After the channel has been prepared, it is opened to the sea and outflow begins. Under artificial breaching, outflow volumes exceed inflow volumes faster than for natural breaching as the initial scouring processes are replaced by the artificial channel, ultimately translating to lower water levels, i.e. under the same size flood event the maximum level reached under natural breach levels is higher than under artificial breach conditions.

Artificial breaching at lower than natural breaching levels, reduce the volume and duration of water flow out to sea, which in turns reduce sediment scouring. This disturbs the long-term erosion/depositional cycles in estuaries as the same amount of marine sediment will still be deposited in side an estuary wave action, while less is removed during an artificial breach than under natural water levels. In the long-term this results in increased sedimentation in the lower estuary.

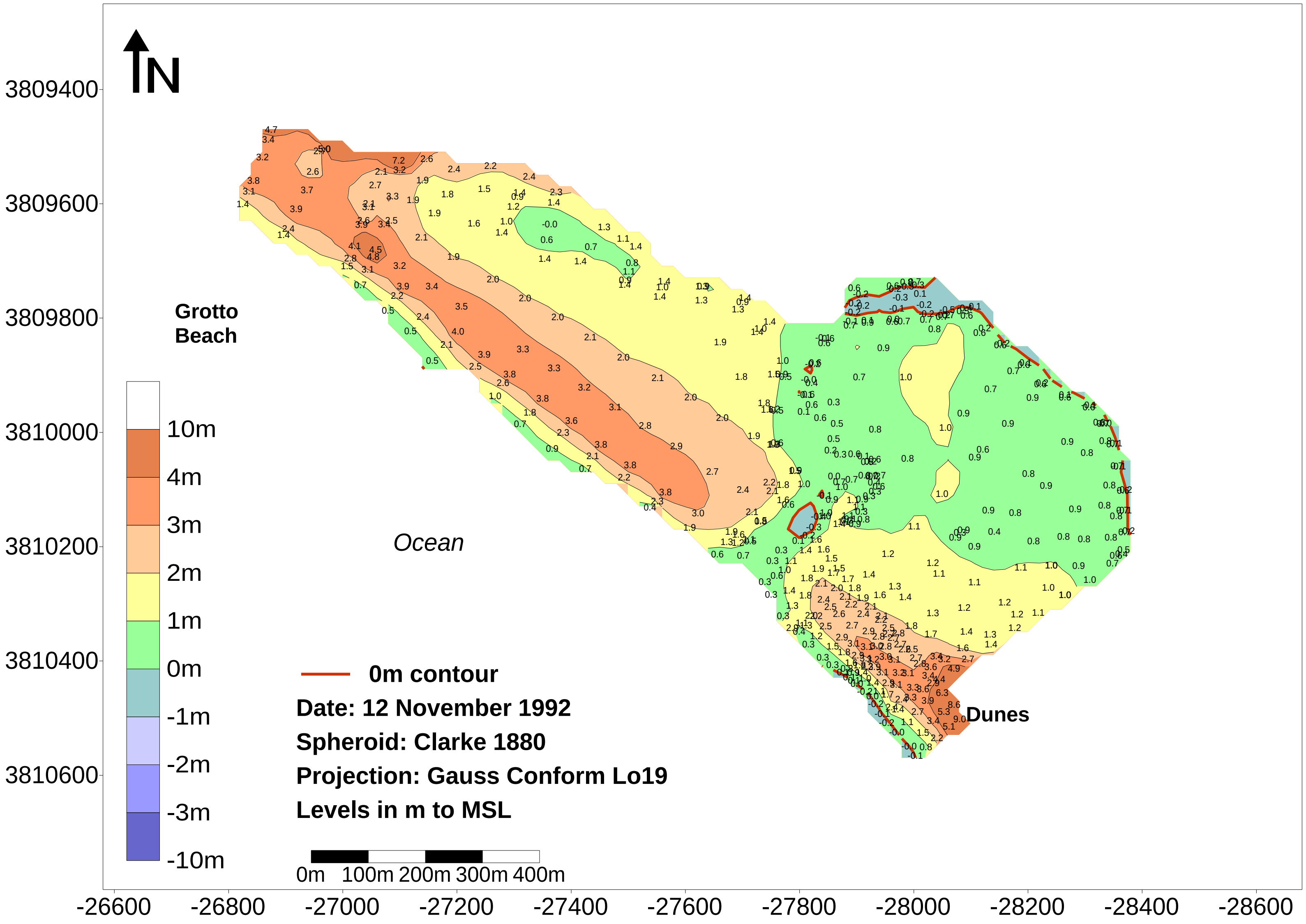


Figure 3.11. Topographical survey of the Klein Estuary lower reaches, 12 November 1992.

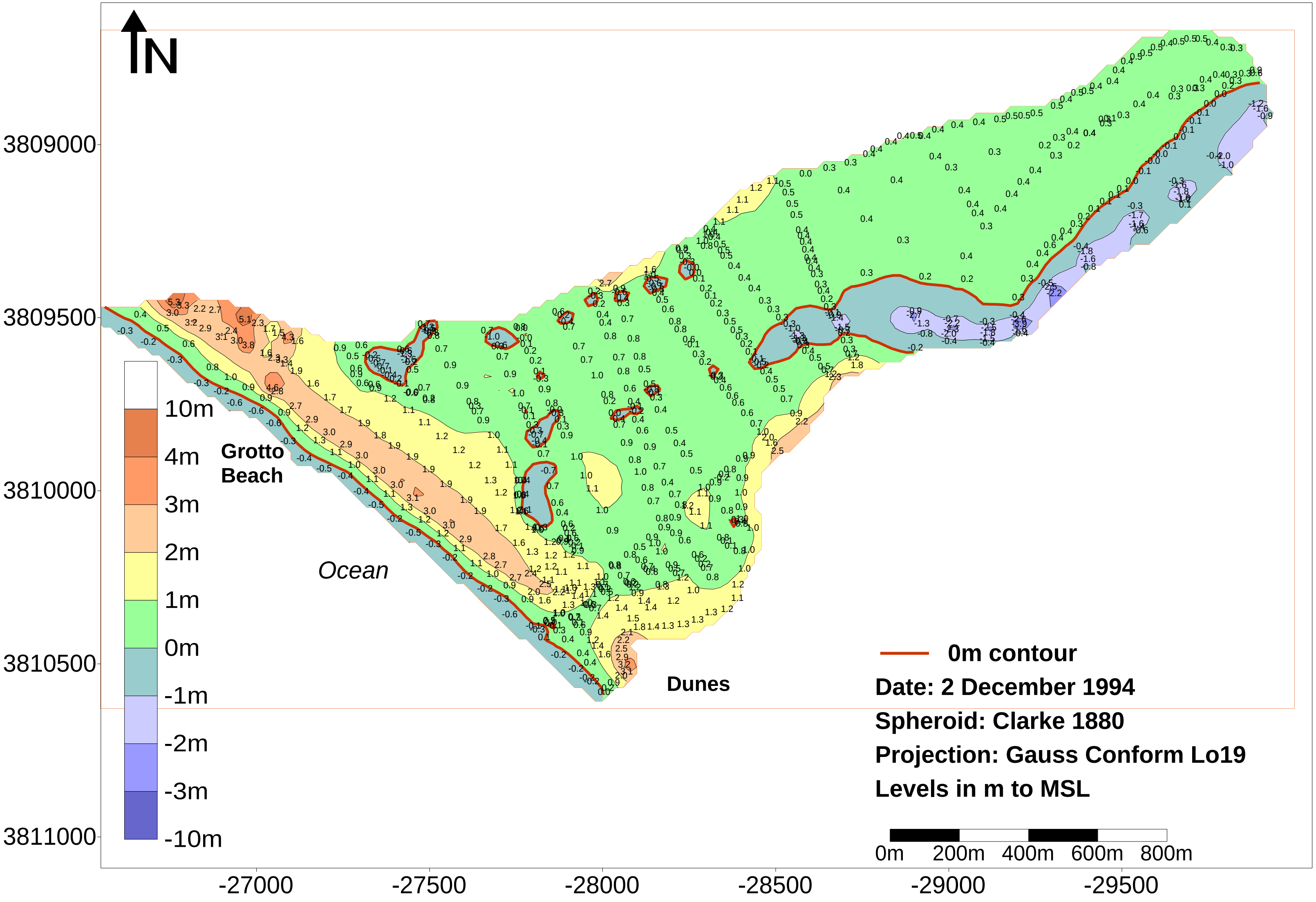


Figure 3.12. Topographical survey of the Klein Estuary lower reaches, 2 December 1994.

3.4.2 Water levels

Under open tidal conditions, water levels in the estuary are substantially lower than when it is closed, ranging between +0.5 and +1.0 m MSL. Table 3.12 provides a summary of mouth state and water levels recorded by the Department of Water and Sanitation at Station G4R004 which is situated at the Yacht Club Jetty in the Klein Estuary. These raw data recordings have to be corrected with -1.47 m to obtain water levels to MSL (as established in CSIR 1997).

In 1997 and 1998 the mouth was artificial mouth breached at water levels of +2.65 and +2.63 m MSL, respectively, which resulted in a considerable increase in the maximum outflow rates during these breaching events. According to available information, no significant damage to property resulted at these breaching levels (CSIR 1998, CSIR 1999), however, it was concluded that problems could have occurred if the waves had been higher along the main waterbody. During these breaching events, observations were made of the effects of high water levels under windy condition on low-lying properties along the vlei edge where the large open water body lends itself to the generation of significant waves. Sand bags and straw bales were installed to protect these properties. Since then, the mouth has been breached again several times at water levels similar to or even higher than those of 1997 and 1998. A summary of breaching water levels between 1979 and 2015 is presented in Figure 3.13, which shows the maximum water levels recorded for each event. There has been a notable upwards trend over the last three decades.

A detailed analysis of the Klein Estuary water levels for the last 35 years (1980-2015) indicates the following:

- The average breaching level is 2.32 m MSL, with a lowest breaching recorded at 1.71 m MSL and the highest at 2.81 m MSL. (Note that in most cases the Klein River Estuary is breached artificially and that this does not represent natural breaching levels, which would have been much higher.)
- The average level at which the Klein Estuary mouth closes is 0.6 m MSL.
- There is a very weak correlation between “breaching water level” and “days open after breaching” indicating that a number of other factors also plays a key role in maintaining a prolonged open mouth state. For example, observations have shown that mouth position plays a significant role in assisting with the mouth remaining open (Figure 3.16 to Figure 3.20). The occurrence of high waves (coastal storms) during unseasonal periods has also resulted in unexpected closures.

Table 3.12. Summary of mouth state, duration of state and related water levels (Source: DWS G4R004)

Open		Closed		Days open	Days closed
Date	Water level to MSL (m)	Date	Water level to MSL (m)		
		08/03/1980	0.51		
18/11/1980	1.71	01/01/1981	0.55	44	255
06/02/1981	1.93	30/05/1981	0.58	113	36
23/07/1981	1.93	06/04/1982	0.53	257	54
05/09/1982	1.74	26/09/1982	0.41	21	152
26/06/1983	1.94	27/09/1983	0.80	93	273
09/09/1984	2.35	1985?			348
30/08/1986	2.71	06/04/1987	0.50	219	
03/10/1987	2.49	14/10/1988	0.55	377	180
08/11/1988	1.90	30/03/1989	0.54	142	25
24/06/1989	1.74	20/11/1989	0.70	149	86
11/06/1990	2.10	29/07/1990	0.73	48	203
02/08/1991	2.49	20/08/1991	0.52	18	369
31/10/1991	1.83	09/12/1991	0.65	39	72
18/07/1992	1.81	03/12/1992	0.54	138	222
19/04/1993	2.32	09/10/1993	0.57	173	137
29/06/1994	2.29	21/12/1994	0.66	175	263
28/07/1995	2.36	30/11/1995	0.73	125	219
27/09/1996	2.25	20/01/1997	0.56	115	302
02/07/1997	2.67	30/10/1997	0.46	120	163
11/06/1998	2.63	13/09/1998	0.75	94	224
15/12/1998	2.37	12/03/1999	0.49	87	93
27/09/1999	2.63	29/02/2000	0.61	155	199
30/10/2000	2.48	11/06/2001	0.70	224	244
26/09/2001	2.54	30/09/2002	0.73	369	107
19/08/2003	2.63	03/12/2003	0.42	106	323
12/04/2005	2.45	29/12/2005	0.51	261	496
16/08/2006	2.73	13/11/2006	0.47	89	230
08/08/2007	2.68	01/02/2008	0.55	177	268
26/09/2008	2.23	26/01/2009	0.50	122	238
14/07/2009	1.96	15/08/2009	0.58	32	169
07/09/2011	2.78	31/12/2011	0.69	115	753
14/08/2012	2.81	22/11/2012	0.70	100	227
10/08/2013	2.66	25/02/2014	0.77	199	261
27/06/2014	2.59	01/12/2014	0.59		122
Average	**2.32**		**0.59**	**141**	**222**
Median	**2.37**		**0.57**	**121**	**222**
Min	**1.71**		**0.41**	**18**	**25**
Max	**2.81**		**0.80**	**377**	**753**

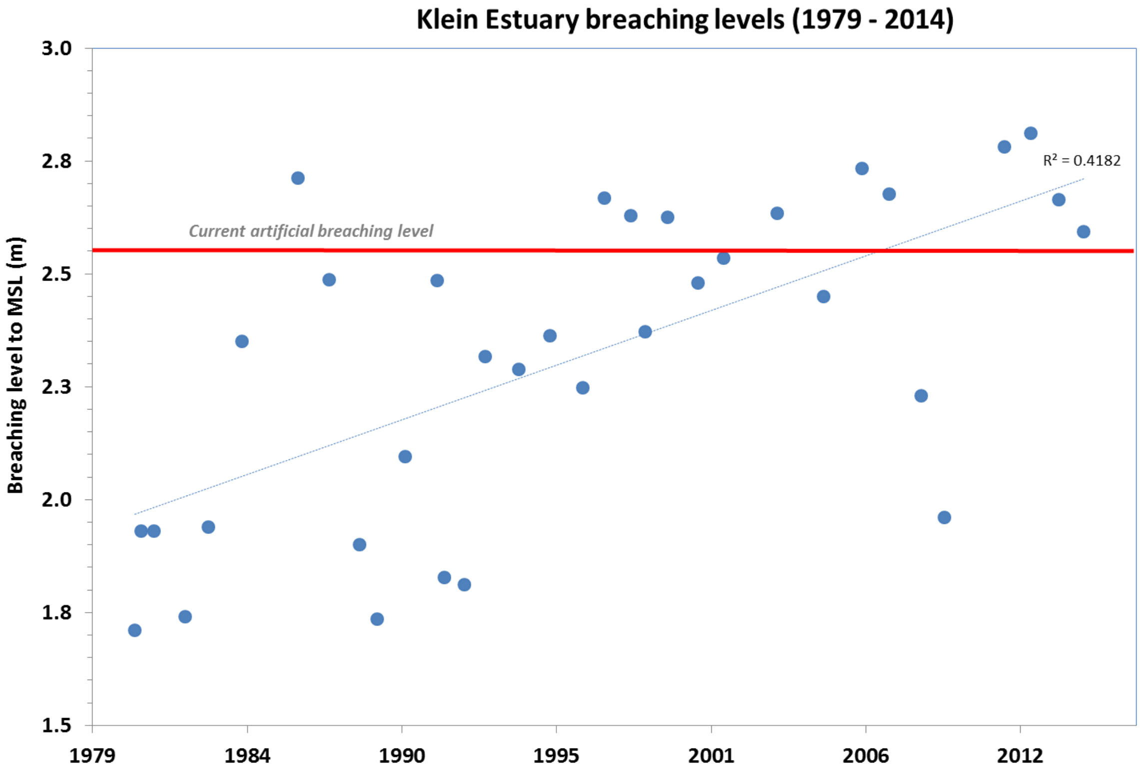


Figure 3.13. A summary of breaching water levels between 1979 and 2014.

3.4.3 Duration of the open period

A detailed analysis of the Klein Estuary mouth behaviour (Table 3.12) over the last 35 years (1980-2015) indicates the following:

- On average the estuary remain open between 3 and 4 months after breaching, with a minimum period of 18 days and a maximum open period of 12.5 months (Figure 3.14).
- The estuary remains closed for about 7 months of the year on average. The longest period of closure was 25 months, associated with the 2010/11 drought. In addition, the estuary also remained closed for more than a year in 1990/91 and 2003/05.
- The highest frequency of breaching occurs between June and September, with a peak towards early spring (Figure 3.15).

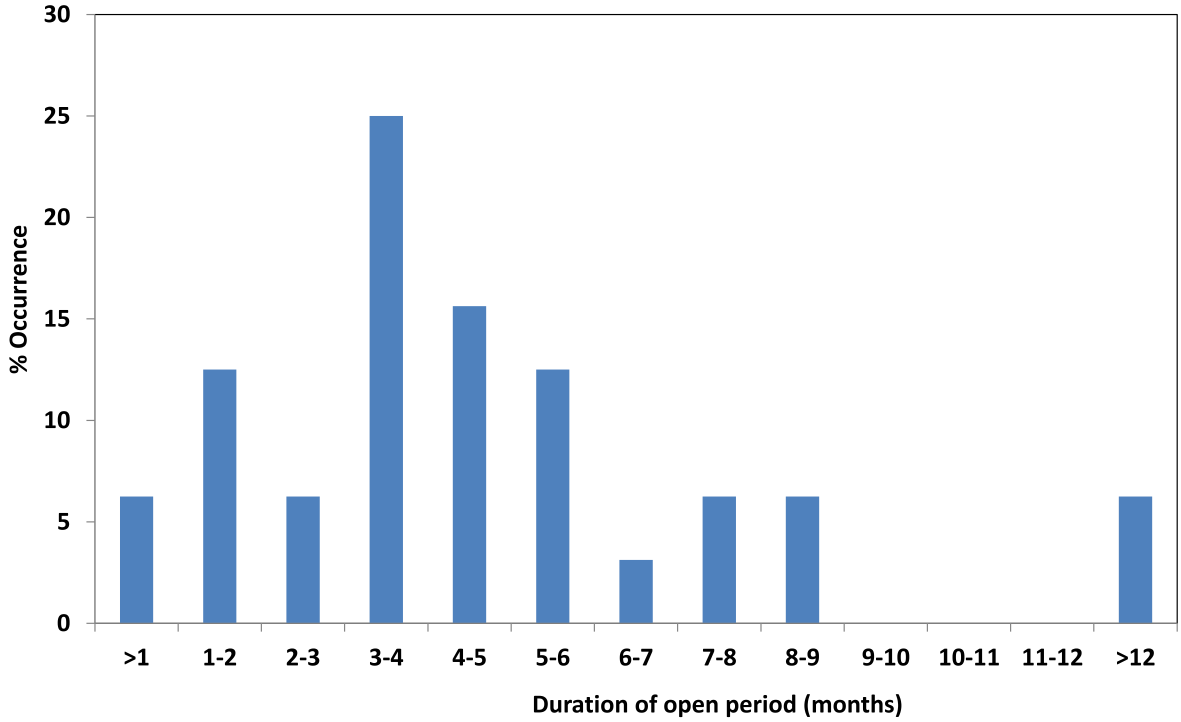


Figure 3.14. Frequency distrubution of the open mouth condition.

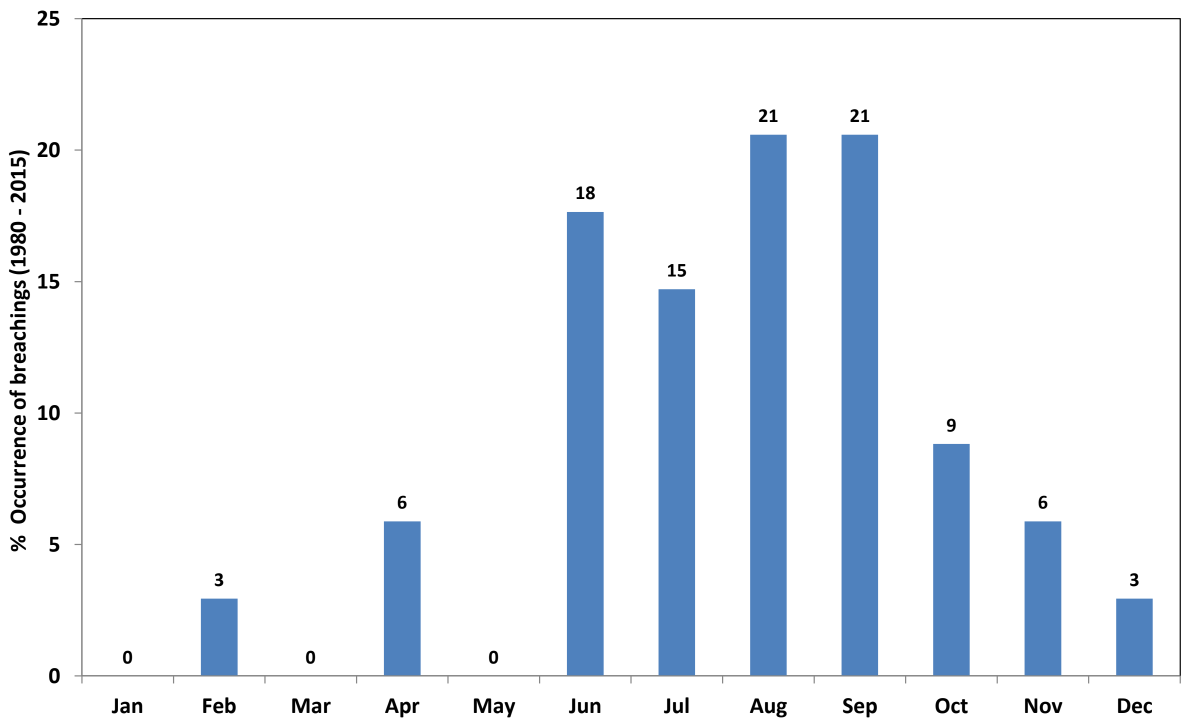


Figure 3.15. Timing of the breaching events.

Figure 3.16. Historical Aerial photographs of the Klein Estuary mouth showing old channels (1938)

Figure 3.17. Historical aerial photograph of the Klein Estuary mouth showing remant channels of other breachings (1961).

Figure 3.18. Historical aerial photographs of the Klein Estuary mouth (1973)

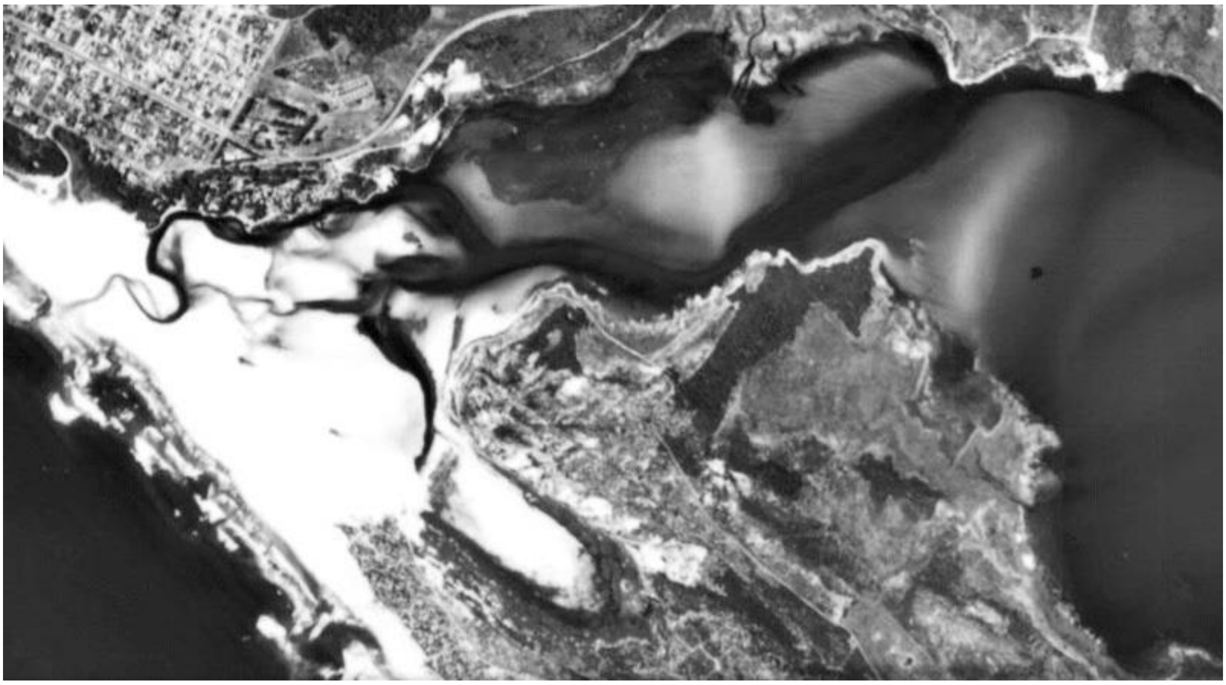


Figure 3.19. Historical aerial photographs of the Klein Estuary mouth showing remant channels of previous breaching to the east (1989).

Figure 3.20. Historical aerial photograph of the Klein Estuary mouth showing remant channels of previous breachings (13 November 2012) (Source: Giorgio Lombardi)

3.4.4 Floods and water levels

During a major flood event, water level in the estuary increases rapidly and the whole process described above occurs over a shorter timeframe. However, as it takes some time for the outflow channel to establish under natural conditions, it can still take several hours before the outflow exceeds inflow from the river. This in turn translates into significantly higher water levels in the estuary under higher inflow conditions even hours after the actual breaching event, due to constricting effect of the outflow channel. The greater the inflow, the longer it will take to reach the equilibrium between inflow and outflow, which means that the maximum water level reached in the Klein Estuary can be up to a metre higher than the berm level (CSIR 1999, 15 December 1998 breaching).

However, while artificial breaching can moderate maximum water levels under low to moderate inflow conditions, the flood attenuation effect is significantly less under major flood conditions. Under high inflow conditions the water levels in the upper estuary are significantly higher than in the lower reaches and vlei as a result of the constraints imposed by the channel.

The flood attenuation effect provided by the large water body of the vlei is significantly reduced in the upper reaches, e.g. the upper reaches are only about 50 m wide in comparison with the vlei which is 650 m to 1500 m wide. Therefore, when a flood comes through, the lack of storage area results in a significant increase in water level in the upper reaches in comparison with the vlei which can distribute the same volume of water over a much larger surface area than is the case for the upper reaches.

3.4.5 Summary of key drivers that maintain an open mouth conditions

After breaching, the normal sediment dynamic processes operating at the mouth of estuaries occur. Turbulence caused by wave action brings sediment into suspension and will also enhance the transport of bottom sediment. With the incoming tide, these sediments are transported into the mouth. The volumes of sediment scoured during breaching will gradually be replaced by marine sediment brought in by the tides, eventually restricting the tidal flows to such an extent that the mouth closes again. Closure of the Klein Estuary mouth will normally occur within a few months after breaching.

In summary, the duration of the period that the mouth is open is determined mainly by the following factors:

- The amount of sediment flushed from the mouth during breaching is determined by the water levels at breaching, higher water levels resulting in longer open mouth conditions.
- The rate at which sediments are transported back into the estuary, is directly related to the occurrence of high waves. High waves do occur more often in winter than in summer. Breaching events that occur in late winter, spring or summer coincide with lower wave regimes, resulting in less sediment entering the system than breaching events that occur during winter.
- The river inflow. An open mouth condition can be maintained for prolonged periods by inflowing river water into the vlei. Reductions in river flow can therefore result in a reduction in open mouth conditions. An assessment of past, present and future run-off conditions is therefore required.
- The mouth of an estuary will normally stay open longer if separate ebb and flood tidal channels can develop. Artificial breaching to far west or east tends to constrict the ebb channel formation.
- How well a breaching event is connected with pervious channels to reduce tidal friction in the lower reaches. Significant scouring potential is lost if the system has to cut new channels in the lower reaches during a breaching event.

3.5 Typical abiotic states

Because the Klein system is not driven by seasonal river inflow patterns, but rather by inter-annual flow patterns, the relationship between "river inflow" and abiotic states can best be described in terms of water levels. Five distinct abiotic states, resulting in the following combination of conditions occurring in the estuary were identified:

State	Name	Description
State 1	Open, marine	The mouth of the estuary is open, with the system under tidal conditions. Salinity in Zone A to C is greater than 30, and is around 20 in Zone D.
State 2	Open, gradient	The mouth of the estuary is open, with the system under tidal conditions. Salinity in Zone A to B is generally greater than 30, and is around 25 and 10 in Zone C and D, respectively.
State 3	Closed, marine	The mouth of the estuary is closed, with the system at water levels below 1.6 m MSL. Salinity in Zone A to C is greater than 30, and is around 25 in Zone D.
State 4	Closed, brackish	The mouth of the estuary is closed, with the system at water levels greater than 1.6 m MSL. Salinity in Zone A to C is between 15 and 20, while in Zone D is between 10 and 15.
State 5	Closed, hyper saline	The mouth of the estuary is closed, with the system at water levels below -1.0 m MSL. All zones in the estuary are hyper saline (salinity 40 to 75). (Note: this is a state that does not occur under the Reference or Present conditions.)

The transitions between the different states will not be instantaneous, but will take place gradually. Breaching can occur due to a slow increase in water level or due to a flood filling up the estuary and triggering a breaching event.

A simple water balance model was developed in which river inflows into the estuary were accumulated to estimate the volume and water level in the system. The volume, in turn was used to evaluate probable mouth conditions and the salinity regime of the system.

Assumptions and limitation for the water balance model are as follows:

- The simulated average monthly flows are of medium confidence.
- At present the Klein estuary is artificially breached at about 2.6 M MSL. However, in the recent past, the estuary was breached between 1.8 and 2.38 m MSL. The Klein Estuary natural breaches at levels up to 3.0 m MSL.
- In general, the higher the water level in the estuary before a breaching event, the more efficient the scouring of sediment in the estuarine channels and mouth area are during breaching, resulting in longer periods of open mouth conditions after the breaching. This relationship is especially important in the case of an estuarine lake as a small increase in breaching level results in significantly more outflow at breaching, i.e. significant increase in scouring potential. This trend could not be verified using the Klein Estuary water level data as artificial breaching at various positions (non-aligned with old channels) and with a range of methods reduce the correlation. It was assumed, however, that the system would have

remained open at least one month longer under natural conditions. This is a conservative estimate.

- There is a relationship between the height of the berm and the period of closure between breachings, i.e. the longer the system was closed the higher the berm. This feature was not incorporated in the water balance model.
- For the purpose of the water balance model mouth closure was taken to occur at a water level of 0.6 m MSL.
- Based on a surface area of about 11 500 000 m^2, the Klein Estuary requires about 23 $x10^6$ m^3 of water to breach at the present breaching level of ~2.6 m MSL. At the natural breaching level of ~ 3.5 m MSL it would have required about 27.6 $x10^6$ m^3 to breach.
- Both seepage from the estuary and ground water inflow from the adjacent dune systems were ignored as no information was available on these inflows. The contribution from direct rainfall falling on the lake and evaporation were, however, factored into the model.
- Overwash was not included in the water balance model as overwash events remain a constant, i.e. sea conditions do not change. As the system remains closed for longer periods under the Future Scenarios, the berm is expected to build up more and overwash will be reduced under Scenario 4 and 5.

To assess the occurrence and duration of the different Abiotic States for the different scenarios, a number of techniques were used, including:

- Colour coding for the full tables of water level data based on the simulated monthly river flow reaching the estuary for the each scenario to highlight the occurrences of the different Abiotic States.
- Summary tables of the occurrences of different flows at 10%ile increments are listed separately to provide a quick comprehensive overview.

Table 3.13. Summary of hydrodynamic characteristics for different abiotic states in the Klein Estuary (differences in state between the Reference condition and Present scenarios due to anthropogenic influences other than flow are indicated).

PARAMETER	State 1: Open, marine*	State 2: Open, gradient*	State 2: Closed, intermediate water level	State 4: Closed, high water level	State 5: Closed, hypersaline
River inflow (m^3/s)	0-3.0	>3.0	All inflow	All inflow, but associated with higher winter flows-	<0.01
Mouth condition	Open	Open	Closed	Closed	Closed
Water level (m to MSL)	0.0-1.3 m MSL	0.0-1.3 m MSL	-1.0 – 1.6 m MSL (Estuary closes at 0.6 m MSL)	>1.6 m MSl	<-1.0
Inundation	None	None	Inundation of intertidal habitat	Inundation of flood plain when full	None
Tidal range	30 cm	30 cm	None	None	None
Dominant circulation process	Tide, wind and river	Tide, wind and river	Wind	Wind and river	Wind
Retention	1-2 weeks	1-2 weeks	Months	Months	Months
Stratification	Well mixed / Well mixed / Well mixed / Stratified	Well mixed / Well mixed / Well mixed / Stratified	Well mixed / Well mixed / Well mixed / Well mixed	Well mixed / Well mixed / Stratified / Highly Stratified	Well mixed / Well mixed / Well mixed / Well mixed
Water column structure (ΔS)**	c / 0 / 0 / 10	0 / 0 / 0 / 10	0 / 0 / 0 / 0	0 / 0 / 10 / 20	0 / 0 / 0 / 0
Salinity	Reference, Present, Sc 1 to 3: 35 / 35 / 35 / 20 Sc 4 to 6: 35 / 35 / 40 / 30	Reference, Present, Sc 1 to 6: 35 / 35 / 25 / 10	Reference, Present, Sc 1 to 6: 30 / 30 / 30 / 25	Reference: 15 / 15 / 15 / 10 Present, Sc 1 to 6: 20 / 20 / 20 / 15	Does not occur under Reference, Present, Sc 1 or 2 Sc 3 and 4: <45 / <45 / <45 / 35 Sc 5: 45-50 / 45-50 / 45-50 / 40 Sc 6: >60 / >60 / >60 / 50

*Assuming mouth position is in the more central position and not far to the west as this leads to a reduction in salinity and early mouth closure.

**ΔS = difference between the salinity of the surface and bottom water

NOTE: For the purpose of this assessment the estuary was sub-divided into 4 zones (surface and bottom) represented from left to right: Zone A: mouth region; Zone B: middle reaches; Zone C: Upper reaches, Zone D: Riverine section above the delta (see Figure 3.6*).*

3.5.1 Occcurence of abiotic states under Present day conditions

A summary of the flow distributions (in 10^6 m^3) for the Present State of Klein Estuary, derived from the 85-year simulated data set, is presented in Table 3.14 below. A graphic representation of the occurrence of the various abiotic states is presented in Figure 3.21. Average water level in the Klein Estuary, based on simulated monthly runoff data for the Present State is provided in Table 3.14. The probability of occurrence of the various abiotic states is indicated by colour coding.

Table 3.14. Simulated monthly flows (in 10^6 m^3) under present state

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	29.32	14.85	6.38	3.36	14.27	10.26	25.03	30.81	48.94	46.46	55.39	46.70
90%ile	6.55	3.46	0.57	0.10	0.12	0.29	2.66	9.71	13.76	21.38	30.13	8.82
80%ile	3.76	1.68	0.17	0.00	0.00	0.09	0.61	2.81	7.61	8.67	17.84	5.99
70%ile	2.45	0.91	0.08	0.00	0.00	0.00	0.23	1.20	4.47	4.76	10.64	4.50
60%ile	2.03	0.67	0.05	0.00	0.00	0.00	0.07	0.49	2.03	3.21	7.64	3.66
50%ile	1.57	0.48	0.04	0.00	0.00	0.00	0.01	0.31	1.02	2.26	5.61	2.95
40%ile	1.31	0.39	0.02	0.00	0.00	0.00	0.00	0.12	0.54	1.60	3.96	2.40
30%ile	1.04	0.33	0.01	0.00	0.00	0.00	0.00	0.04	0.26	1.17	2.16	1.99
20%ile	0.79	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.79	1.43	1.62
10%ile	0.49	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.43	0.65	1.14
1%ile	0.29	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.32	0.38

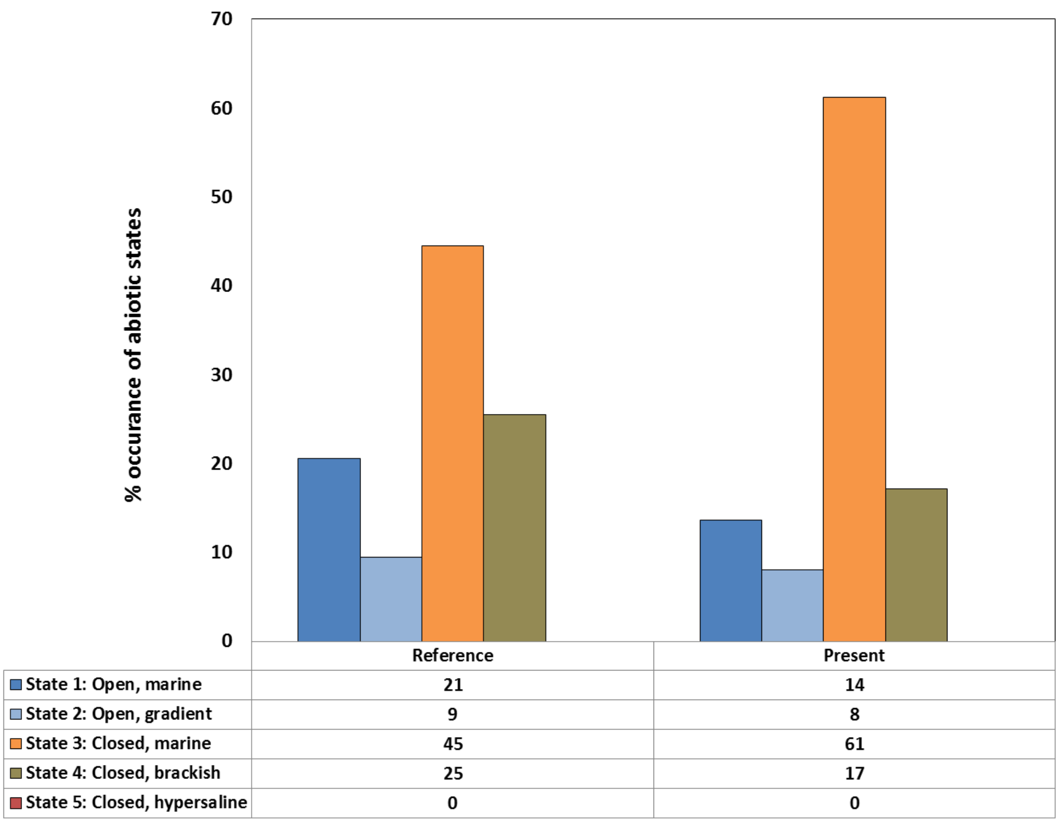


Figure 3.21. Percentage occurrence of the various abiotic states under Present and Refrence conditions.

Table 3.15. Klein Estuary simulated average monthly water level (m to MSL) under the present state. Colour coding indicates likley occurrence of different abiotic states as follows: State 1: Open

marine, 2: Open gradient, 3: Closed marine, 4: Closed brakish, 5: Closed hypersaline.

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.619	0.529	0.408	0.262	0.155	0.037	-0.015	-0.047	0.000	0.000	0.000	0.000
1921	0.681	0.581	0.462	0.422	0.289	0.236	0.178	0.167	1.078	1.142	1.607	1.704
1922	1.707	0.000	0.000	0.000	0.000	0.481	0.769	1.608	2.120	0.000	0.000	0.000
1923	0.000	1.755	1.654	1.504	1.372	1.276	1.223	1.177	2.312	2.401	0.000	0.000
1924	0.000	0.000	0.497	0.357	0.213	0.093	0.038	-0.007	0.000	0.000	0.000	0.000
1925	0.798	0.758	0.613	0.443	0.310	0.200	0.138	0.147	0.186	2.045	2.379	2.550
1926	0.000	0.000	0.000	0.000	0.483	0.366	0.309	0.387	0.415	0.428	0.965	1.027
1927	0.985	0.912	0.786	0.642	0.500	0.399	0.321	0.285	0.410	0.394	0.454	0.571
1928	0.525	0.469	0.327	0.156	0.020	-0.071	-0.113	-0.114	-0.106	0.674	0.855	0.920
1929	0.887	0.809	0.683	0.534	0.428	0.363	0.328	0.365	0.374	0.392	0.719	1.185
1930	1.246	1.201	1.046	0.884	0.746	0.637	1.006	1.039	1.041	1.719	0.000	0.000
1931	0.000	0.000	0.468	0.316	0.220	0.102	0.026	0.088	0.207	0.309	0.366	0.000
1932	0.000	0.000	0.000	0.435	0.294	0.186	0.126	0.138	0.902	1.256	0.000	0.000
1933	0.000	0.000	0.435	0.265	0.125	0.014	-0.068	-0.082	-0.095	0.086	0.752	1.488
1934	1.746	1.700	1.542	1.380	1.236	1.126	1.137	1.439	1.648	1.838	1.950	2.091
1935	2.111	2.058	1.922	1.821	1.690	1.573	1.513	1.581	1.622	1.713	1.781	1.870
1936	1.874	1.848	1.757	1.602	1.459	1.369	1.323	1.297	1.847	0.000	0.000	0.000
1937	0.000	0.525	0.388	0.246	0.102	0.083	0.094	0.218	0.293	0.414	0.642	2.537
1938	0.000	0.000	0.000	0.000	0.520	0.447	0.430	0.437	0.432	0.643	1.293	1.461
1939	1.473	1.383	1.243	1.083	2.580	0.000	0.000	0.000	0.000	0.786	0.877	1.004
1940	0.999	1.091	0.943	0.788	0.643	0.520	1.361	2.299	0.000	0.000	0.000	0.000
1941	0.925	0.892	0.768	0.619	0.473	0.362	0.309	0.726	1.450	1.602	1.780	1.935
1942	1.958	1.852	1.770	2.490	2.404	2.336	2.320	2.391	2.441	0.000	0.000	0.000
1943	0.000	0.611	0.472	0.314	0.163	0.041	-0.014	0.589	2.496	0.000	0.000	0.000
1944	0.000	0.536	0.394	0.221	0.070	-0.051	-0.075	0.000	0.000	0.000	0.000	1.218
1945	2.226	2.354	2.223	2.065	1.923	1.972	1.917	1.920	1.982	2.037	2.087	2.464
1946	2.527	2.415	2.261	2.092	1.949	1.883	1.836	1.845	1.858	0.000	0.000	0.000
1947	0.000	0.525	0.367	0.210	0.066	0.073	0.058	0.052	0.127	0.314	0.353	0.424
1948	0.000	0.000	0.000	0.000	0.459	0.331	0.417	0.497	0.533	0.599	0.844	0.977
1949	0.994	1.144	1.012	0.842	0.693	0.568	0.587	0.572	0.577	0.973	1.008	1.187
1950	1.252	1.531	1.436	1.389	1.251	1.150	1.309	1.373	0.000	0.000	0.000	0.000
1951	1.151	1.102	0.947	0.786	0.650	0.534	0.490	0.523	0.577	0.807	1.677	0.000
1952	0.000	0.000	0.000	0.443	0.303	0.178	0.342	0.392	0.505	0.876	1.037	1.104
1953	1.091	1.135	0.982	0.819	0.689	0.591	0.590	0.000	0.000	0.000	0.000	1.208
1954	1.284	1.219	1.075	0.911	0.000	0.000	0.000	0.000	0.735	1.755	0.000	0.000
1955	0.000	0.000	0.462	0.293	0.167	0.083	0.036	1.209	2.134	2.547	0.000	0.000
1956	0.000	0.000	0.574	0.417	0.307	0.217	0.184	2.185	0.000	0.000	0.000	0.000
1957	0.000	0.801	0.643	0.470	0.362	0.317	0.299	2.096	2.364	2.452	0.000	0.000
1958	0.000	0.000	0.443	0.298	0.160	0.072	1.831	0.000	0.000	0.000	0.000	0.984
1959	1.357	1.317	1.165	1.008	0.862	0.763	0.717	0.760	1.123	1.276	1.365	1.412
1960	1.378	1.256	1.159	1.122	0.987	0.881	0.828	0.866	0.979	1.102	1.499	1.890
1961	1.984	1.883	1.727	1.611	1.478	1.431	1.454	1.442	0.000	0.000	0.000	0.000
1962	1.780	1.924	1.776	1.626	1.486	1.376	1.339	1.307	1.329	1.874	0.000	0.000
1963	0.000	0.000	0.491	0.333	0.215	0.135	0.090	0.084	1.285	1.644	0.000	0.000
1964	0.000	0.000	0.579	0.420	0.308	0.251	0.224	0.305	0.342	0.421	0.491	0.497
1965	0.479	0.372	0.234	0.069	-0.073	-0.183	-0.180	-0.170	-0.163	0.060	1.123	1.414
1966	1.456	1.351	1.196	1.032	0.889	0.792	2.156	2.308	0.000	0.000	0.000	0.000
1967	0.685	0.626	0.471	0.326	0.194	0.078	0.026	0.077	0.544	0.689	1.081	1.198
1968	1.249	1.168	1.011	0.871	0.736	0.620	0.651	0.632	0.687	0.706	0.731	0.720
1969	0.714	0.597	0.433	0.268	0.151	0.020	-0.056	-0.059	0.094	0.372	1.199	1.421
1970	1.512	1.425	1.284	1.116	0.976	0.861	0.823	0.825	0.911	1.205	2.292	2.486
1971	2.548	2.471	2.351	2.192	2.061	1.958	2.071	2.149	2.252	2.356	0.000	0.000
1972	0.000	0.000	0.449	0.283	0.133	0.010	-0.058	-0.035	-0.030	0.040	0.066	0.103
1973	0.054	-0.045	-0.188	-0.347	-0.488	-0.608	-0.687	-0.421	-0.379	-0.366	0.000	0.000
1974	0.000	0.000	0.444	0.293	0.143	0.022	-0.021	0.217	0.240	0.588	1.331	1.490
1975	1.627	1.553	1.386	1.212	1.074	0.975	1.073	1.119	0.000	0.000	0.000	0.000
1976	0.813	0.979	0.863	0.696	0.681	0.577	0.542	0.886	1.273	0.000	0.000	0.000
1977	0.000	0.540	0.532	0.384	0.261	0.170	0.132	0.124	0.121	0.604	1.203	1.391
1978	1.459	1.364	1.243	1.103	1.756	1.743	1.668	1.882	2.048	2.293	2.590	0.000
1979	0.000	0.000	0.000	0.448	0.313	0.182	0.136	0.165	0.475	0.493	0.532	0.533
1980	0.509	0.735	0.652	0.840	0.774	0.720	1.049	1.095	1.127	2.022	0.000	0.000
1981	0.000	0.000	0.457	0.311	0.166	0.069	1.170	1.294	1.445	1.492	1.610	1.676
1982	1.639	1.519	1.368	1.208	1.189	1.106	1.058	2.377	0.000	0.000	0.000	0.000
1983	0.735	0.691	0.537	0.370	0.236	0.133	0.099	1.099	1.223	1.357	1.436	1.637
1984	1.933	1.867	1.805	1.753	1.648	1.548	1.597	1.583	1.622	0.000	0.000	0.000
1985	0.000	0.546	0.391	0.221	0.091	0.034	-0.013	-0.046	-0.005	0.077	0.000	0.000
1986	0.000	0.000	0.459	0.302	0.174	0.052	0.118	0.195	0.343	0.438	1.221	1.710
1987	1.818	1.710	1.575	1.404	1.276	1.156	1.264	1.294	1.417	1.471	1.976	2.144
1988	2.212	2.120	1.974	1.817	1.688	2.258	0.000	0.000	0.000	0.000	0.000	2.140
1989	0.000	0.584	0.435	0.283	0.182	0.065	0.600	1.037	2.407	0.000	0.000	0.000
1990	0.000	0.516	0.364	0.216	0.068	-0.044	-0.109	-0.062	0.083	2.399	0.000	0.000
1991	0.000	0.000	0.460	0.304	0.182	0.074	0.064	0.174	0.529	0.712	1.114	1.701
1992	2.391	2.457	2.321	2.163	2.069	1.952	0.000	0.000	0.000	0.000	2.277	0.000
1993	0.000	0.501	0.383	0.227	0.094	-0.020	-0.024	0.016	0.000	0.000	0.000	0.000
1994	0.656	0.552	0.578	0.441	0.300	0.390	0.404	0.863	1.021	1.412	0.000	0.000
1995	0.000	0.000	0.737	0.589	0.473	0.362	0.291	0.273	0.383	0.893	1.082	1.341
1996	2.598	0.000	0.000	0.000	0.000	0.475	0.447	1.543	1.927	2.068	2.303	2.398
1997	2.428	2.566	2.418	2.268	2.125	2.030	2.144	0.000	0.000	0.000	0.000	0.779
1998	0.759	1.125	0.000	0.000	0.000	0.000	0.622	0.631	0.640	0.639	0.859	1.848
1999	1.926	1.823	1.689	1.560	1.414	1.397	1.346	1.355	1.369	1.674	1.787	2.000
2000	2.008	1.894	1.749	1.592	1.453	1.329	1.288	1.302	1.296	0.000	0.000	0.000
2001	0.000	0.543	0.396	0.589	0.512	0.390	0.363	0.484	0.790	1.506	2.584	0.000
2002	0.000	0.000	0.000	0.456	0.320	0.000	0.000	0.000	0.000	0.651	0.000	0.000
2003	0.000	0.000	0.467	0.326	0.194	0.088	0.045	0.017	0.064	0.267	0.333	0.353
2004	2.134	2.158	2.021	1.953	1.817	1.695	0.000	0.000	0.000	0.000	0.932	1.132

3.5.2 Occcurence of abiotic states under the Reference condition

A summary of the occurrences of flow distributions (average in 10^6 m^3) for the Reference condition, derived from the 85-year simulated data set, is presented in Table 3.16 below. A graphic representation of the occurrence of the various abiotic states is presented in Figure 3.21. Average water level in the Klein Estuary, based on simulated monthly runoff data for the Reference conditions is presented in Table 3.18.

Table 3.16. Simulated monthly flows (in 10^6 m^3) under Refrence conditions

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
99%ile	32.61	16.66	8.10	5.15	18.44	13.72	28.71	35.40	54.78	50.66	61.75	50.69	175.51
90%ile	8.11	5.00	1.52	0.75	0.82	1.27	4.16	12.94	15.99	24.41	32.91	10.62	102.21
80%ile	4.88	3.04	0.88	0.34	0.33	0.67	1.68	4.96	9.32	10.89	20.08	7.43	76.15
70%ile	3.60	2.09	0.67	0.29	0.19	0.22	0.99	2.46	5.96	6.82	12.73	5.63	56.82
60%ile	3.18	1.72	0.61	0.25	0.16	0.17	0.64	1.54	3.13	4.73	9.53	5.02	50.58
50%ile	2.71	1.40	0.55	0.24	0.14	0.13	0.48	1.15	2.29	3.41	7.41	4.13	41.22
40%ile	2.42	1.29	0.52	0.22	0.13	0.11	0.33	0.74	1.54	2.86	5.20	3.47	31.36
30%ile	2.11	1.18	0.48	0.20	0.12	0.10	0.17	0.56	1.08	2.30	3.52	3.09	28.58
20%ile	1.85	1.04	0.44	0.19	0.11	0.09	0.14	0.40	0.90	1.73	2.58	2.66	24.19
10%ile	1.49	0.89	0.39	0.16	0.09	0.07	0.09	0.32	0.62	1.40	1.78	2.18	18.66
1%ile	1.13	0.58	0.22	0.10	0.06	0.05	0.05	0.14	0.35	0.65	1.22	1.27	10.17

3.5.3 Hydrodynamic health

Scores for the various components of the hydrodynamic health of the Klein estuary (mouth condition and abiotic states, stratification, water retention time, and water level) and overall hydrodynamic health are presented in Table 3.17.

Table 3.17. Hydrodynamics score

<table>
<tr><th>Variable</th><th>Score</th><th>Motivation</th><th>% non-flow related</th><th>Conf.</th></tr>
<tr><td>a. Mouth condition and abiotic states</td><td>72</td><td>Under the reference state the estuary was open for about 30% of the time. At Present it is open for about 22% of the time.</td><td>60</td><td>L</td></tr>
<tr><td>b. Stratification</td><td>92</td><td>Estimated average salinity difference between surface and bottom salinity in water column:<table><tr><th></th><th>Zone A</th><th>Zone B</th><th>Zone C</th><th>Zone D</th></tr><tr><td>Reference</td><td>0</td><td>0</td><td>3</td><td>7</td></tr><tr><td>Present</td><td>0</td><td>0</td><td>2</td><td>5</td></tr></table></td><td>0</td><td>L</td></tr>
<tr><td>c. Water retention time</td><td>89</td><td>The % occurrence of closed mouth conditions were taken as indicative of retention time.</td><td>60</td><td>L</td></tr>
<tr><td>d. Water level</td><td>97</td><td>On average, water level is about 10 cm lower than Reference</td><td>600</td><td>L</td></tr>
<tr><td>Hydrodynamics and mouth conditions score</td><td>72</td><td>Min (a- d)</td><td></td><td>L</td></tr>
<tr><td>Adjusted score</td><td>89</td><td>Excludes non-flow related effects</td><td></td><td></td></tr>
</table>

$**\Delta S$ = difference between the salinity of the surface and bottom water

Table 3.18. Klein Estuary average monthly water level (m to MSL) under the Reference condition, Colour coding indicates likley occurrence of different abiotic states as follows: State 1: Open marine, 2: Open gradient, 3: Closed marine, 4: Closed brakish, 5: Closed hypersaline..

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.628	0.585	0.495	0.366	0.271	0.162	0.161	0.154	0.000	0.000	0.000	0.000
1921	0.000	0.561	0.477	0.473	0.365	0.356	0.322	0.335	1.503	1.632	2.173	2.349
1922	2.429	0.000	0.000	0.000	0.000	0.000	0.980	1.967	2.524	0.000	0.000	0.000
1923	0.000	0.000	0.584	0.460	0.341	0.252	0.207	0.172	1.590	1.741	2.648	2.966
1924	0.000	0.000	0.000	0.000	0.000	0.485	0.442	0.411	0.000	0.000	0.000	0.000
1925	0.000	0.646	0.546	0.391	0.264	0.158	0.098	0.139	0.223	2.368	2.743	2.983
1926	0.000	0.000	0.000	0.000	0.000	0.491	0.443	0.610	0.718	0.796	1.511	1.648
1927	1.681	1.669	1.578	1.451	1.316	1.222	1.152	1.120	1.360	1.386	1.534	1.765
1928	1.790	1.800	1.694	1.533	1.400	1.313	1.288	1.310	1.366	2.407	2.672	2.822
1929	2.867	2.839	2.752	2.624	2.535	2.501	2.488	2.552	2.594	2.653	0.000	0.000
1930	0.000	0.000	0.000	0.452	0.320	0.216	0.792	0.871	0.921	1.733	2.986	0.000
1931	0.000	0.000	0.000	0.000	0.529	0.423	0.353	0.463	0.681	0.882	1.024	0.000
1932	0.000	0.000	0.000	0.000	0.465	0.360	0.304	0.370	1.398	1.832	0.000	0.000
1933	0.000	0.000	0.000	0.438	0.304	0.195	0.115	0.114	0.133	0.450	1.314	2.160
1934	2.489	2.532	2.415	2.265	2.126	2.019	2.096	2.581	2.858	0.000	0.000	0.000
1935	0.000	0.000	0.505	0.454	0.342	0.234	0.183	0.323	0.418	0.593	0.749	0.933
1936	1.018	1.072	1.037	0.905	0.769	0.686	0.649	0.633	1.406	0.000	0.000	0.000
1937	0.000	0.000	0.504	0.383	0.248	0.250	0.303	0.535	0.683	0.890	1.208	0.000
1938	0.000	0.000	0.000	0.000	0.583	0.538	0.555	0.618	0.663	1.003	1.756	1.990
1939	2.081	2.055	1.949	1.801	0.000	0.000	0.000	0.000	0.000	0.838	0.999	1.187
1940	1.261	1.425	1.317	1.177	1.040	0.919	1.940	2.956	0.000	0.000	0.000	0.000
1941	0.000	0.645	0.566	0.439	0.302	0.197	0.152	0.780	1.588	1.799	2.037	2.259
1942	2.365	2.315	2.302	0.000	0.000	0.000	0.000	0.000	0.717	0.951	1.317	1.644
1943	1.815	1.905	1.812	1.672	1.528	1.411	1.360	2.201	0.000	0.000	0.000	0.000
1944	0.000	0.599	0.491	0.333	0.187	0.069	0.090	0.000	0.000	0.000	0.000	0.000
1945	1.642	1.843	1.757	1.617	1.483	1.643	1.619	1.651	1.767	1.895	2.018	2.488
1946	2.624	2.566	2.433	2.271	2.130	2.119	2.091	2.139	2.204	0.000	0.000	0.000
1947	0.000	0.000	0.475	0.328	0.189	0.250	0.261	0.285	0.409	0.721	0.835	0.997
1948	0.000	0.000	0.000	0.000	0.000	0.475	0.673	0.810	0.901	1.040	1.391	1.595
1949	1.693	1.931	1.847	1.694	1.550	1.428	1.519	1.530	1.563	2.150	2.259	2.516
1950	2.661	0.000	0.000	0.000	0.000	0.000	0.885	0.994	0.000	0.000	0.000	0.000
1951	0.000	0.623	0.504	0.354	0.225	0.114	0.079	0.160	0.272	0.653	1.614	2.879
1952	0.000	0.000	0.000	0.000	0.000	0.480	0.770	0.877	1.048	1.509	1.739	1.885
1953	1.949	2.077	1.966	1.815	1.692	1.601	1.630	0.000	0.000	0.000	0.000	0.000
1954	0.751	0.747	0.637	0.487	2.869	2.917	2.895	2.903	0.000	0.000	0.000	0.000
1955	0.000	0.668	0.572	0.418	0.299	0.224	0.189	1.613	2.551	2.994	0.000	0.000
1956	0.000	0.000	0.000	0.471	0.382	0.312	0.303	2.512	0.000	0.000	0.000	0.000
1957	0.000	0.873	0.751	0.591	0.491	0.521	0.552	2.563	2.872	0.000	0.000	0.000
1958	0.000	0.000	0.477	0.346	0.218	0.140	2.100	2.997	0.000	0.000	0.000	0.000
1959	0.000	0.649	0.536	0.397	0.261	0.167	0.130	0.250	0.818	1.046	1.216	1.341
1960	1.384	1.309	1.243	1.252	1.140	1.039	0.994	1.068	1.227	1.406	1.978	2.465
1961	2.642	2.611	2.485	2.390	2.267	2.263	2.345	2.375	0.000	0.000	0.000	0.000
1962	0.000	0.824	0.727	0.599	0.468	0.365	0.336	0.359	0.440	1.186	2.322	2.538
1963	2.632	2.606	2.535	2.394	2.283	2.243	2.218	2.241	0.000	0.000	0.000	0.000
1964	0.000	1.261	1.273	1.135	1.037	1.019	1.028	1.196	1.293	1.457	1.611	1.695
1965	1.757	1.707	1.603	1.452	1.316	1.211	1.237	1.273	1.312	1.610	2.875	0.000
1966	0.000	0.000	0.000	0.000	0.460	0.365	1.995	2.180	2.894	0.000	0.000	0.000
1967	0.000	0.000	0.482	0.351	0.227	0.116	0.070	0.206	0.878	1.099	1.575	1.765
1968	1.889	1.875	1.751	1.626	1.500	1.393	1.494	1.505	1.630	1.705	1.797	1.851
1969	1.913	1.842	1.694	1.532	1.455	1.330	1.257	1.279	1.539	1.973	0.000	0.000
1970	0.000	0.000	0.000	0.443	0.308	0.199	0.168	0.203	0.361	0.808	2.124	2.387
1971	2.528	2.519	2.442	2.303	2.185	2.093	2.337	2.501	2.688	2.866	0.000	0.000
1972	0.000	0.000	0.000	0.444	0.299	0.178	0.112	0.154	0.182	0.327	0.421	0.543
1973	0.558	0.501	0.375	0.222	0.085	-0.032	-0.108	0.312	0.404	0.472	0.000	0.000
1974	0.000	0.000	0.000	0.467	0.324	0.207	0.168	0.566	0.642	1.110	1.983	2.214
1975	2.422	2.416	2.281	2.115	1.981	1.895	2.035	2.144	0.000	0.000	0.000	0.000
1976	0.000	0.847	0.795	0.658	0.733	0.661	0.663	1.131	1.581	0.000	0.000	0.000
1977	0.000	0.000	0.650	0.531	0.419	0.338	0.323	0.335	0.357	0.894	1.640	1.896
1978	2.041	2.012	1.925	1.802	2.579	2.580	2.519	2.839	0.000	0.000	0.000	0.000
1979	0.000	0.631	0.529	0.393	0.268	0.141	0.100	0.167	0.663	0.749	0.861	0.933
1980	0.974	1.274	1.227	1.497	1.474	1.498	1.890	1.987	2.080	0.000	0.000	0.000
1981	0.000	0.000	0.495	0.365	0.227	0.133	1.442	1.585	1.798	1.906	2.080	2.214
1982	2.238	2.156	2.020	1.864	1.902	1.841	1.803	0.000	0.000	0.000	0.000	0.000
1983	0.822	0.841	0.722	0.567	0.439	0.343	0.321	1.580	1.755	1.944	2.088	2.351
1984	2.720	2.737	2.773	2.789	2.716	2.662	2.786	2.816	2.906	0.000	0.000	0.000
1985	0.000	0.000	0.485	0.329	0.212	0.205	0.187	0.179	0.291	0.454	0.000	0.000
1986	0.000	0.000	0.000	0.458	0.337	0.220	0.382	0.535	0.806	0.986	1.894	2.466
1987	2.662	2.615	2.509	2.348	2.225	2.108	2.248	2.312	2.525	2.648	0.000	0.000
1988	0.000	0.000	0.000	0.456	0.334	1.131	2.964	0.000	0.000	0.000	0.000	0.000
1989	1.116	1.191	1.086	0.949	0.876	0.770	1.520	2.018	0.000	0.000	0.000	0.000
1990	0.000	0.576	0.461	0.329	0.190	0.081	0.021	0.103	0.351	2.930	0.000	0.000
1991	0.000	0.000	0.000	0.459	0.344	0.243	0.282	0.490	0.972	1.220	1.712	2.395
1992	0.000	0.000	0.000	0.000	0.000	0.495	0.000	0.000	0.000	0.000	0.000	1.009
1993	1.092	1.044	0.958	0.817	0.690	0.583	0.627	0.746	0.000	0.000	0.000	0.000
1994	0.000	0.555	0.665	0.559	0.428	0.526	0.553	1.199	1.420	1.872	0.000	0.000
1995	0.000	0.000	0.000	0.489	0.393	0.297	0.238	0.234	0.440	1.086	1.339	1.655
1996	0.000	0.000	0.000	0.000	0.000	0.480	0.496	1.843	2.271	2.474	2.765	2.937
1997	0.000	0.000	0.000	0.000	0.000	0.510	0.688	0.000	0.000	0.000	0.000	0.000
1998	0.659	1.076	0.000	0.000	0.000	0.000	0.000	0.642	0.692	0.738	1.016	2.131
1999	2.278	2.232	2.125	2.015	1.878	1.913	1.885	1.916	1.963	2.463	2.652	2.949
2000	0.000	0.000	0.000	0.000	0.000	0.478	0.447	0.505	0.534	2.186	2.932	0.000
2001	0.000	0.000	0.000	0.000	0.547	0.438	0.437	0.674	1.043	1.848	2.998	0.000
2002	0.000	0.000	0.000	0.000	0.472	0.000	0.000	0.000	0.000	0.000	0.000	1.207
2003	1.421	1.406	1.311	1.190	1.068	0.969	0.977	0.971	1.068	1.394	1.541	1.641
2004	0.000	0.000	0.000	0.000	0.000	0.486	0.000	0.000	0.000	0.000	0.000	0.873

3.6 Water quality

3.6.1 Baseline description and Reference condition

3.6.1.1 Salinity

Table 3.19 provides a summary of 25 salinity profiles taken in the Klein estuary over a 15-year period. The observed salinity data was averaged for the respective zones, A to D. From this dataset it is clear that that the Klein Estuary is strongly marine dominated, with salinity between 30 and 38 recorded for both the open and closed mouth phases. The data set also shows very little stratification, attributed to very effective wind mixing under open and closed mouth conditions. Stratification is mostly confined to Zone D under higher flow conditions.

If a sound connection with the sea is established following breaching (not possible when the mouth is breached in the 2014/15 far west position), near marine conditions (salinity 30-35) establish themselves with in a month or two of breaching. Under extended open mouth conditions, coupled with the present limited base flows, hyper-salinity (36-39) can develop in the upper reaches of Zone B and Zone C.

After a few months, physical processes will cause mouth closure in the late summer or early winter. A number of observations indicate that runoff is generally still low during this period, leading to medium to low water levels (<1.8 m MSL) and while maintaining the high salinity values (30-35). If closure occurs early in summer, hypersalinity may even develop during this state (salinity 36-39). Later, when seasonal winter rainfall elevates the water levels above 1.8 m MSL, salinity decreases to below 20.

Only under significant inflow conditions, generally associated with mouth breaching, does a full salinity gradient develop from the Zone A to D (A=25-30, B=10-20, C=15-5, D=1). However, these conditions are only maintained for a few weeks at a time, before the systems starts reverting to the more dominant open marine condition.

However, similar low salinity conditions can also develop when the entrance channel is too restrictive to allow for effective tidal flushing, i.e. the inlet channel is to too narrow and shallow (breaching at low water levels or not aligned with historical channels) or too extended (western position add an addition 500 m to inlet length) as a result of inappropriate breaching practices. However, under this condition, these lower salinities will persist, resulting in a limited/slow increase in salinity over time. Marine conditions (salinity >30) throughout the system may not even be achieved as the mouth tends to close prematurely under these conditions.

3.6.1.2 Temperature

Temperatures in the Klein estuary exhibit a strong seasonal signal with highest temperatures in summer (23-28^{o}C) and lowest during winter (12-17^{o}C), based on measurements collected during 7 surveys between 2010 and 2013 (Figure 3.22). This would have been similar to the Reference condition.

Table 3.19. Summary of the average observed salinity distrubution in the four zones in relation to mouth state and water levels (1999 to 2014).

No	Date	Salinity (PSU)				Water level (m to msl)	Mouth State	Days since…
		Zone A	Zone B	Zone C	Zone D			
1	19-Dec-99	14	16	8		0.67	Open	84
2	05-Feb-00	35	35	36	16	0.57	Open	131
3	29-Mar-00	31	32	32	18	0.88	Closed	29
4	19-Apr-00	32	32	32	14	0.92	Closed	50
5	05-Jun-00	29	30	30	14	0.99	Closed	97
6	**02-Jul-00**	29	28	19	11	**1.14**	**Closed**	**124**
7	**28-Aug-00**	**19**	**18**	**18**	**17**	**2.03**	**Closed**	**181**
8	07-Nov-00	34	26	15	15	0.49	Open	8
9	02-Mar-01	34	36	36	22	0.53	Open	123
10	06-Apr-01	35	36	36	28	0.62	Open	158
11	30-Dec-01	34	34	33		0.61	Open	95
12	04-Jun-02	32	32	32			Open	251
13	**29-Mar-03**	**17**	**16**	**15**	**3**	**1.55**	**Closed**	**180**
14	**15-Feb-10**	**19**	**19**	**19**	**16**	**1.69**	**Closed**	**184**
15	27-Sep-11	25	23	16	2	1.91	Open	20
16	25-Oct-11	34	31	28	13	1.91	Open	48
17	29-Feb-12	37	38	33	26	0.50	Closed	60
18	21-May-12	35	37	32	25	0.50	Closed	142
19	**31-Jul-12**	**22**	**22**	**21**	**14**	**1.50**	**Closed**	**213**
20	28-Aug-12	24	9	6	1	0.69	Open	14
21	11-Sep-12	30	15	13	1	0.96	Open	28
22	19-Sep-12	28	17	9	1		Open	36
23	14-Nov-12	25	16	15	1	0.83	Open	92
24	19-Mar-13	26	23	16	3	0.867	Closed	117
25	06-Oct-14	32	22	20	19	0.867	Open	101

During the open mouth state especially in summer, temperatures in the lower estuary can decrease significantly (14-15^{o}C) as a result of upwelling at sea, when colder seawater enters the estuary during high tide, as was observed in February 1989 (De Decker 1989).

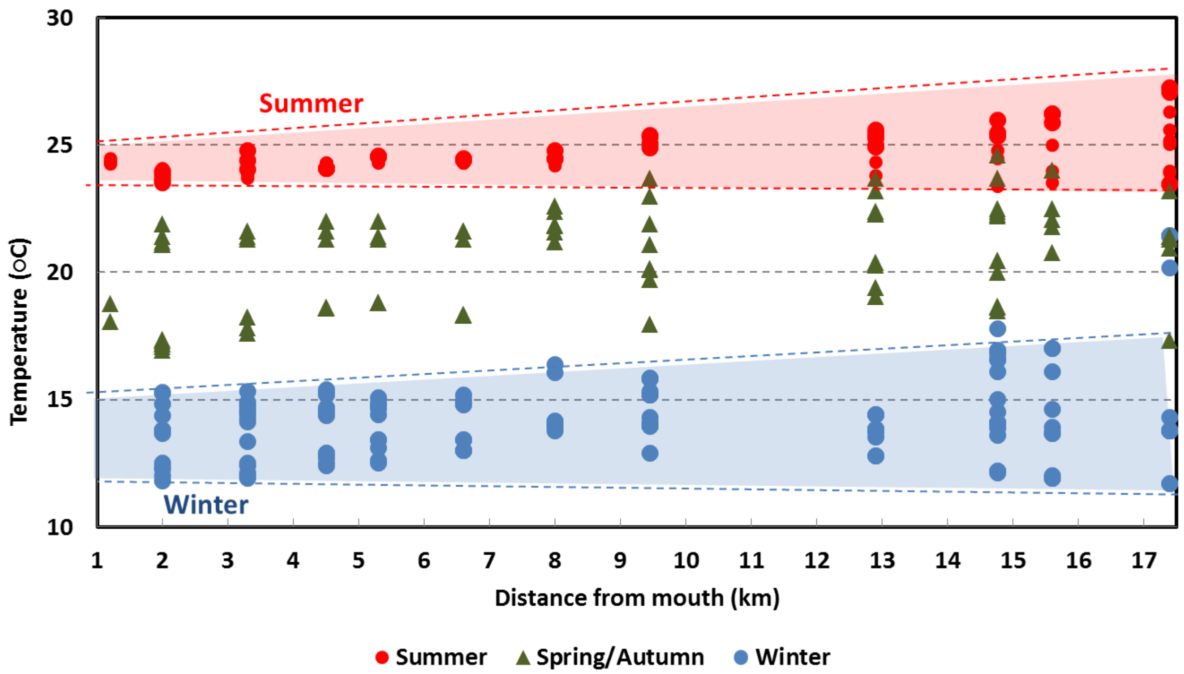


Figure 3.22. Temperature patterns measured in the Klein Estuary (Unpublished data: DAFF, CSIR and Overberg Municipality).

3.6.1.3 pH

A significant part of lower Klein River catchment drains humic-rich areas (black water systems) that would have resulted in acidic (low pH) and low inorganic nutrient concentrations entering the estuary in the natural state. Historic pH data collected from the Klein River (DSW station G6H4) highlight these lower pH levels as well as a tendency for pH to increase over the period 1980 to present (Figure 3.23). However, DWS (M Silberbauer, pers. comm.) noted that the sudden "jump" in pH levels between 1989 and 1990 may reflect a change in method and should be interpreted with caution.

pH levels measured in the estuary between 2010 and 2013 typically ranged between 7.7 and 8.5 (unpublished data: DAFF, CSIR, Overberg Municipality) with lower pH levels mostly associated with the fresher, upper reaches of the estuary.

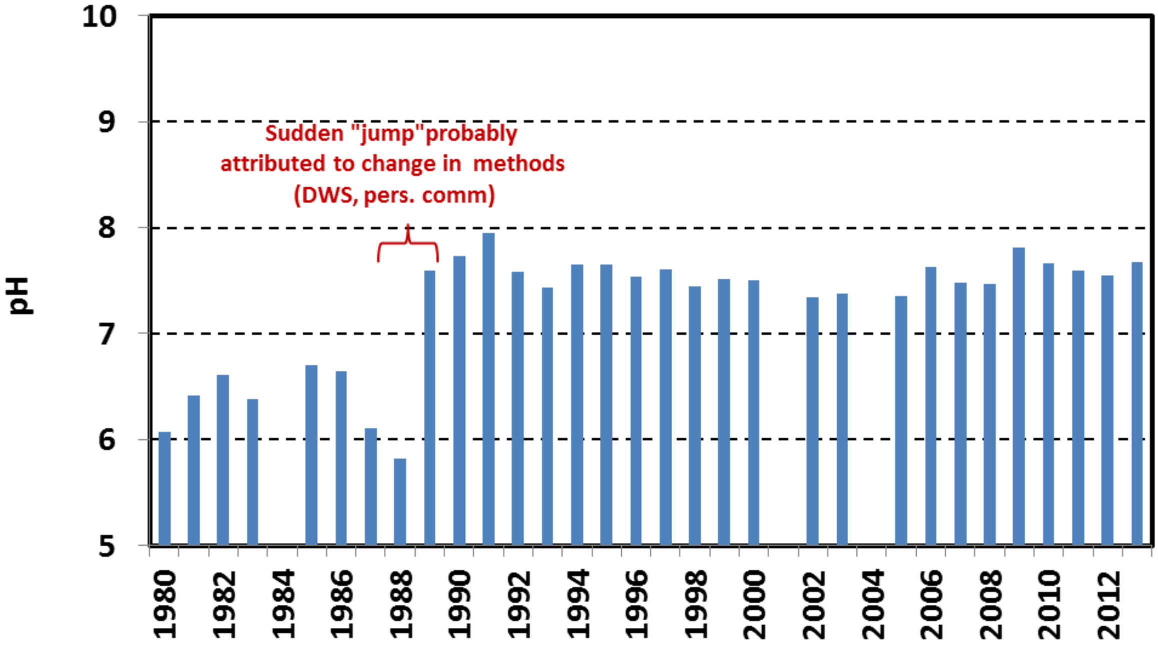


Figure 3.23. Average annual pH levels measured in thev Klein River (DWS Station: G6H4) between 1980 and 2013 (https://www.dwaf.gov.za/iwqs/wms/data/WMS_pri_txt.asp)

3.6.1.4 Turbidity

Inflow to the Klein Estuary has the characteristic “brown” colour associated with catchment draining humic-rich areas. While this affects visibility (especially in the fresher areas), turbidity levels (typically associated with colloidal/solid particles in the water column) in these systems are very low (<10 NTU), possibly slightly elevated during high flow (~NTU 20).

Results suggest that in the Present state (Figure 3.24) turbidity in the estuary during high flows (e.g. Aug 2012) tends to be higher (~20-30 NTU) than expected under Reference conditions (~10 NTU). However, the influence of lower turbidity seawater remains evident in the lower, more saline areas of the estuary during the Aug 2012 survey. During intermediate flows, turbidity varied (<10 to 30 NTU), but during lower flows periods the system remained relatively clear (<10 NTU).

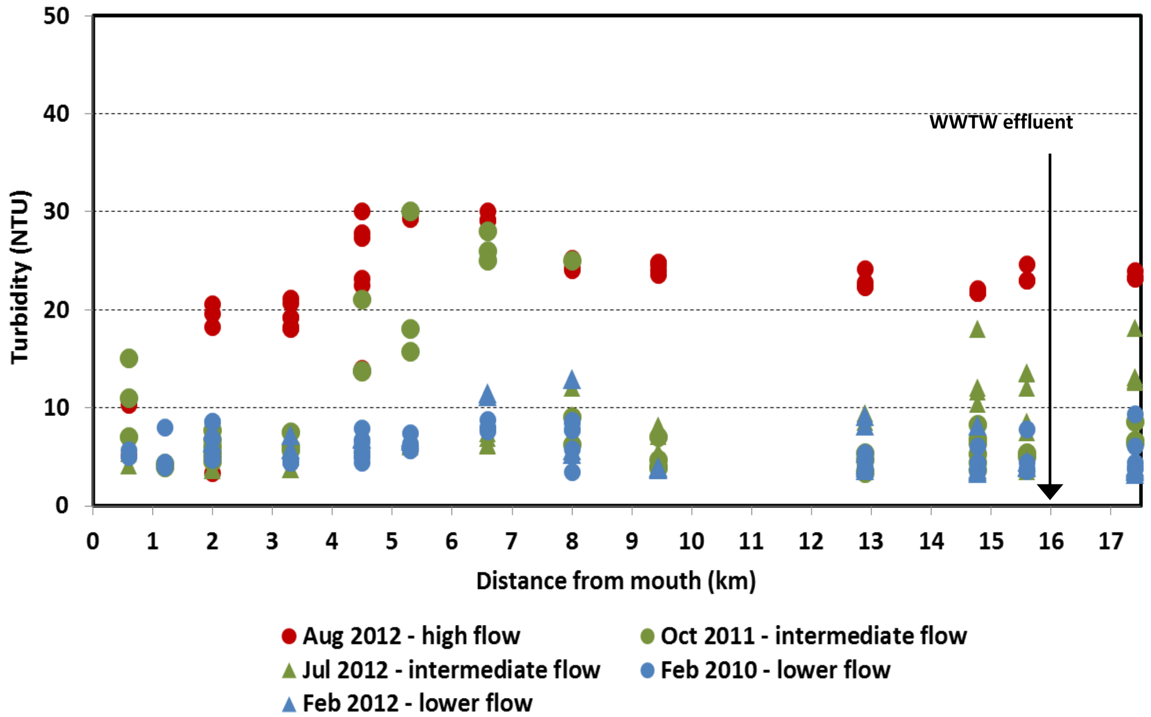


Figure 3.24. Turbidity patterns measured in the Klein Estuary (unpublished data: DAFF, CSIR and Overberg Municipality)

3.6.1.5 Dissolved oxygen

Under the Reference condition, low nutrient input (typical of a black water system) and strong marine influence would have resulted in a well-oxygenated system (>6 mg/ℓ) for most of the time. Dissolved oxygen (DO) measurements collected in the Klein Estuary (Figure 3.25) under current conditions, suggest that in the open, tidal state (high flow) the systems is still well-oxygenated (>6 mg/ℓ) (e.g. Aug 2012).

However, during closed periods when the system is brackish (i.e. long residence times with significant amounts of enriched freshwater still entering the estuary), DO can to drop to 4 mg/ℓ, even below 2 mg/ℓ, especially in the upper estuary and in the deeper bottom waters of the lower estuary. The low DO levels (2 mg/ℓ) measured in the lower estuary during Feb 2010 was measured at night, with supersaturated conditions (12 mg/ℓ) occurring during the day. These DO levels were strongly influenced by photosynthetic/respiration patterns associated with dense algal beds present in that part of the estuary at the time. During the closed periods when little freshwater enters the estuary (e.g. Feb 2012), DO levels remain stress (mostly below 6 mg/l), but not as severe as in the brackish closed states.

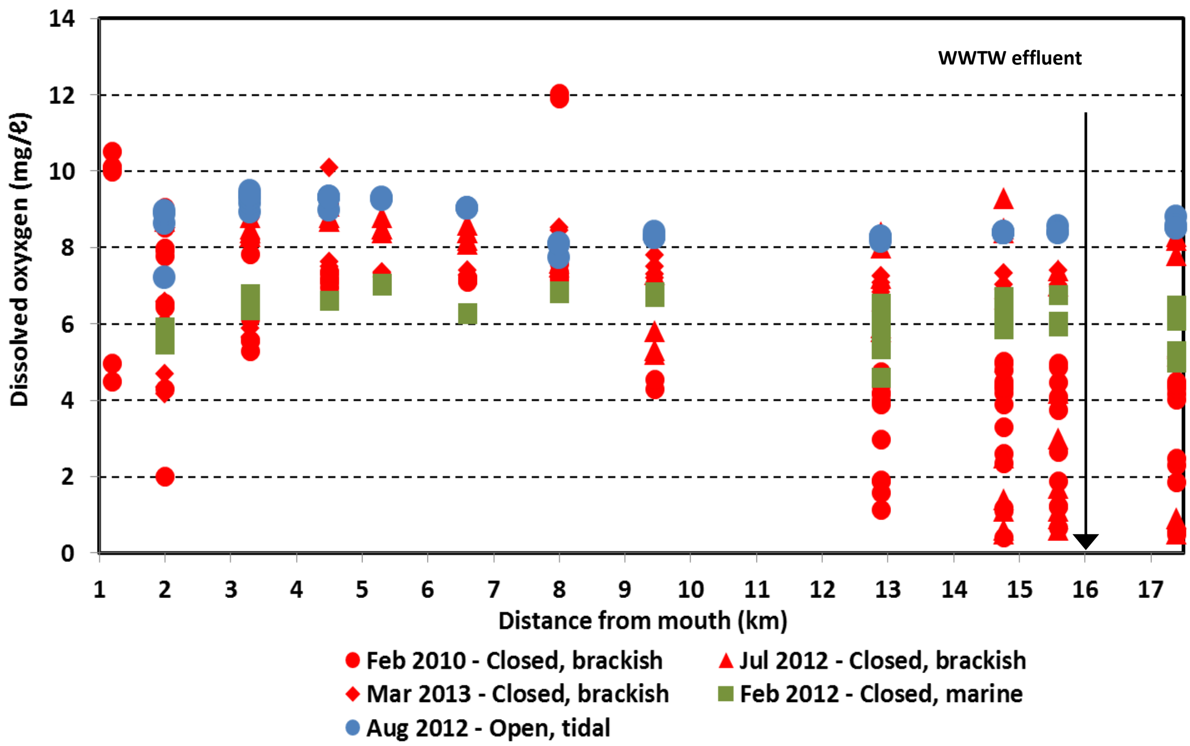


Figure 3.25. Dissolved oxygen patterns measured in the Klein Estuary (unpublished data: DAFF, CSIR and Overberg Municipality)

3.6.1.6 Inorganic nutrients

Under the Reference condition, inorganic nutrient concentrations in the river inflow is expected to have been low (characteristic of black water system) e.g. DIN <50 µg/ℓ and DIP <10µg/ℓ (De Villiers & Thiart 2007). However, extensive agricultural activities in the catchment have increased inorganic nutrient loading in river inflow markedly as is evident in the average annual and average monthly concentrations (1980 to 2013) measured at DSW station G6H4 upstream of the head of the estuary (above Standford WWTW effluent discharge) (Figure 3.26). Marked variations are evident in average annual DIN and DIP concentration in river inflow over the period 1980 to 2013 (Figure 3.26). Of note is the strong seasonal signal in the DIN concentrations (mostly NO_x-N) showing a distinct peak at the onset of the higher flow periods (late autumn/winter), probably a result of increased diffuse runoff from fertilised agricultural areas.

Under the present state, another major source of organic matter and inorganic nutrients to the Klein Estuary is the effluent discharge from the Stanford WWTW. Data obtained from the DWS WQ monitoring programme (G40-1000010167) showed large variability in effluent nutrient concentrations between 2010 and 2013 averaging at ~18 000 µg/ℓ and ~6 400 µg/ℓ, for DIN (NO_x-N and NH_4-N) and DIP, respectively. The daily volume discharged to the estuary was assumed as 500 m^3 (or 0.006 m^3/s).

Recent data on inorganic nutrient concentration in the Klein Estuary is very limited (May 2012) (unpublished data: Overberg Municipality) (Figure 3.27). At the time DIN concentrations throughout the estuary were depleted (<50 µg/ℓ). However, DIP concentration showed a different pattern where concentration increased moving upstream into less saline water – presumably linked to inflow from WWTW effluent. The depleted state of DIN can be explained if it is the limiting nutrient in this system already taken up primary production in mostly "old" seawater (salinity in lower estuary 35) introduced during the preceding open state (Jan 2012). Upwelling (when colder, high nutrient water reaches the surface along the coast) does occur along this part of the coast and can influence nutrient concentrations in the lower estuary during the open state. For example, in Feb 1989 high NO_x-N and DIP concentrations (300 µg/ℓ and 80 µg/ℓ, respectively) measured in cold seawater (15^{o}C) in the lower estuary were attributed to such an event (De Decker 1989).

Based on an understanding of available data sets (mostly data from DWS monitoring programme), the following concentrations were assumed for the WWTW and seasonal river inflow:

PARAMETER	WWTW	River (summer)	River (spring)	River (winter)
DIN (µg/ℓ)	18 000	400	800	1 500
DIP (µg/ℓ)	6 000	20	25	30
Turbidity (NTU)	20	10	20	30

Proportional contributions of WWTW inflow and catchment inflow were used to calculate resultant concentrations in freshwater inflow under the various states, scenarios and treatment levels. For DIN, DIP and turbidity, salinity was mostly used as proxy to calculate the resultant concentration in each of the zones under various scenarios, assuming mixing as the dominant driver (Table 3.21). Dissolved oxygen, however, could not be estimated in this manner, being a strongly non-conservative parameter. DO concentrations, therefore, were derived from available data. For this study, concentrations in seawater were assumed as follows:

- DIN: 50 µg/ℓ (100 µg/ℓ during open states in summer to account for occasional upwelling)
- DIP: 10 µg/ℓ (20 µg/ℓ during open states in summer to account for occasional upwelling)
- Turbidity: 10 NTU
- DO: 8 mg/ℓ

A summary of the key water quality characteristics assumed for the various states, in each of the three zones is presented in Table 3.20. These were derived from the water quality data above, as well as expert opinion and experience gained from specialists at the EWR workshop.

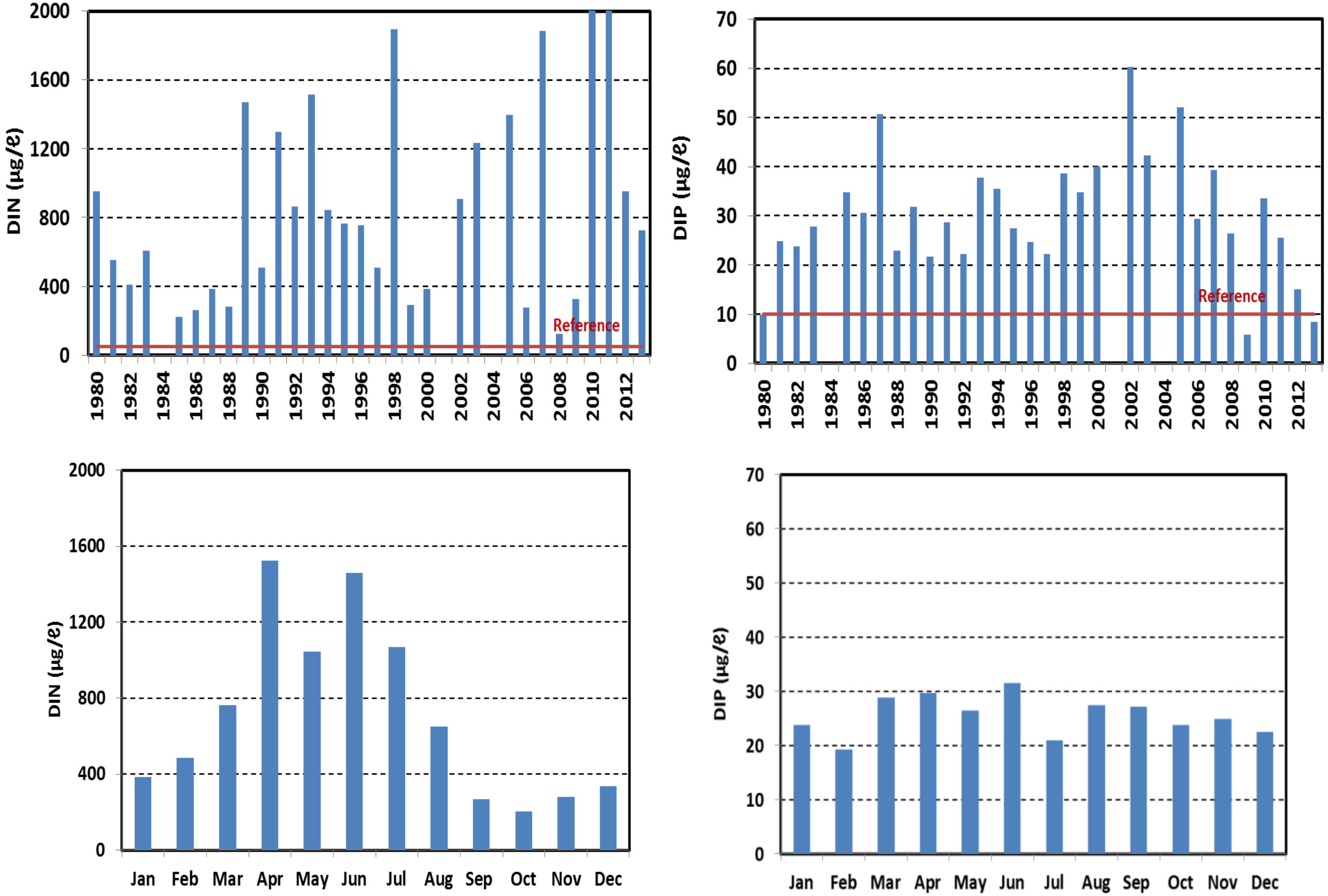


Figure 3.26. **Average annual (top) and average monthly (bottom) DIN (NO_x-N plus NH_4-N) and DIP concentrations measured in the Klein River (DWS Station: G6H4) between 1980 and 2013 (https://www.dwaf.gov.za/iwqs/wms/data/WMS_pri_txt.asp).**

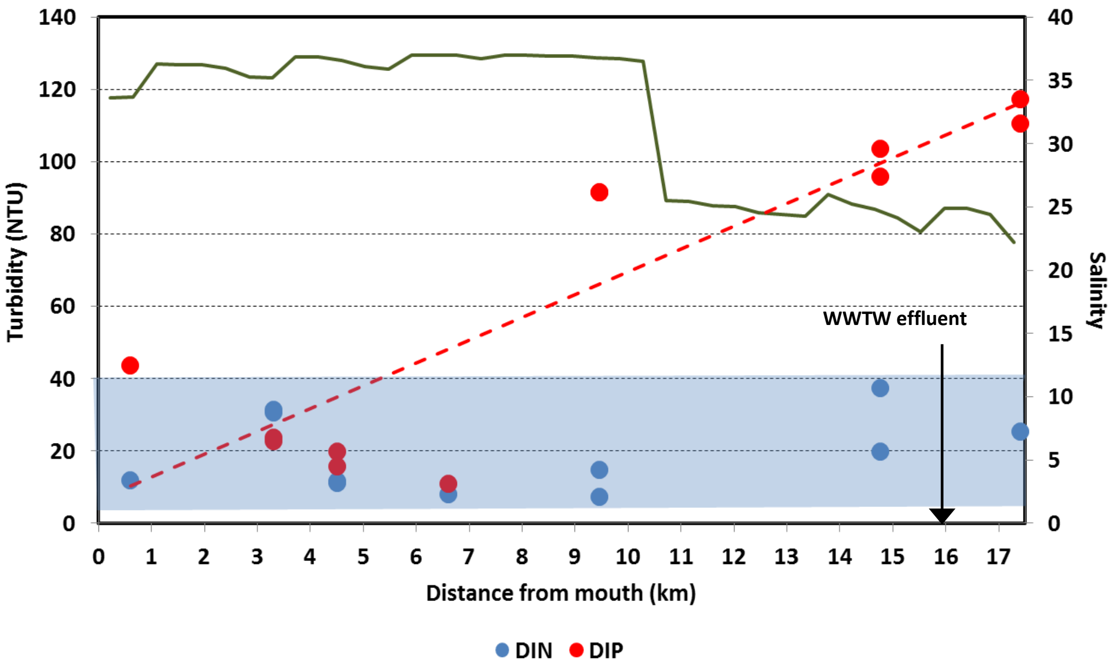


Figure 3.27. DIN and DIP distribution pattern measured in the Klein Estuary in May 2012 (Salinity on secondary axis represented by solid green line) (unpublished data: Overberg Municipality)

Table 3.20 Summary of key water quality characteristics within various abiotic states for selected flow scenarios in the Klein estuary (characteristics for abiotic states that do not occur under a flow scenario were not included).

SALINITY	State 1: Open marine				State 2: Open REI				State 3: Closed, marine				State 4: Closed brackish				State 5: Closed hypersaline			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Reference	35	35	35	20	35	35	25	10	30	30	30	25	15	15	15	10				
Present	35	35	35	20	35	35	25	10	30	30	30	25	20	20	20	15				
Scenario 1	35	35	35	20	35	35	25	10	30	30	30	25	20	20	20	15				
Scenario 2	35	35	35	20	35	35	25	10	30	30	30	25	20	20	20	15				
Scenario 3	35	35	35	20	35	35	25	10	30	30	30	25	20	20	20	15	<45	<45	<45	35
Scenario 4	35	35	40	30	35	35	25	10	30	30	30	25	20	20	20	15	<45	<45	<45	35
Scenario 5	35	35	40	30	35	35	25	10	30	30	30	25	20	20	20	15	45-50	45-50	45-50	40
Scenario 6	35	35	40	30	35	35	25	10	30	30	30	25	20	20	20	15	>50	>50	>50	50

DISSOLVED OXYGEN (mg/ℓ)	State 1: Open marine				State 2: Open REI				State 3: Closed, marine				State 4: Closed brackish				State 5: Closed hypersaline			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Reference	8	8	8	6	8	8	8	8	6	6	6	6	6	6	6	6				
Present	8	6	6	4	8	6	6	6	5	6	5	4	4	5	5	2				
Scenario 1	8	6	6	4	8	6	6	6	5	6	5	4	4	5	5	2				
Scenario 2	8	6	6	4	8	6	6	6	5	6	5	4	4	5	5	2				
Scenario 3	8	6	6	4	8	6	6	6	5	6	5	4	4	5	5	2	5	6	5	4
Scenario 4	8	6	6	4	8	6	6	6	5	6	5	4	4	5	5	2	5	6	5	4
Scenario 5	8	6	6	4	8	6	6	6	5	6	5	4	4	5	5	2	5	6	5	2
Scenario 6	8	6	6	4	8	6	6	6	5	6	5	4	4	5	5	2	4	5	4	2

TURBIDITY (NTU)	State 1: Open marine				State 2: Open REI				State 3: Closed, marine				State 4: Closed brackish				State 5: Closed hypersaline			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Reference	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10				
Present	10	10	10	10	10	10	10	10	10	10	10	10	20	20	20	20				
Scenario 1	10	10	10	10	10	10	10	10	10	10	10	10	20	20	20	20				
Scenario 2	10	10	10	10	10	10	10	10	10	10	10	10	20	20	20	20				
Scenario 3	10	10	10	10	10	10	10	10	10	10	10	10	20	20	20	20	10	10	10	10
Scenario 4	10	10	10	10	10	10	10	10	10	10	10	10	20	20	20	20	10	10	10	10
Scenario 5	10	10	10	10	10	10	10	10	10	10	10	10	20	20	20	20	10	10	10	10
Scenario 6	10	10	10	10	10	10	10	10	10	10	10	10	20	20	20	20	10	10	10	10

DIN (µg/ℓ)	State 1: Open marine				State 2: Open REI				State 3: Closed, marine				State 4: Closed brackish				State 5: Closed hypersaline			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Reference	100	50	50	50	50	50	50	50	50	50	50	50	50	50	50	100				
Present	100	50	50	400	50	50	300	600	100	100	100	200	700	700	700	900				
Scenario 1	100	50	50	400	50	50	300	600	100	100	100	200	700	700	700	900				
Scenario 2	100	50	50	400	50	50	300	600	100	100	100	200	700	700	700	900				
Scenario 3	100	50	50	400	50	50	300	600	100	100	100	200	700	700	700	900	100	100	100	100
Scenario 4	100	50	50	200	50	50	300	600	100	100	100	200	700	700	700	900	100	100	100	300
Scenario 5	100	50	50	200	50	50	300	600	100	100	100	200	700	700	700	900	100	100	100	900
Scenario 6	100	50	50	200	50	50	300	600	100	100	100	200	700	700	700	900	300	300	300	1400

DIP (µg/ℓ)	State 1: Open marine				State 2: Open REI				State 3: Closed, marine				State 4: Closed brackish				State 5: Closed hypersaline			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Reference	20	10	10	10	10	10	10	10	10	10	10	10	10	10	10	20				
Present	20	10	10	20	10	10	20	30	20	20	20	30	20	20	20	30				
Scenario 1	20	10	10	20	10	10	20	30	20	20	20	30	20	20	20	30				
Scenario 2	20	10	10	20	10	10	20	30	20	20	20	30	20	20	20	30				
Scenario 3	20	10	10	20	10	10	20	30	20	20	20	30	20	20	20	30	20	20	20	20
Scenario 4	20	10	10	10	10	10	20	30	20	20	20	30	20	20	20	30	20	20	20	100
Scenario 5	20	10	10	10	10	10	20	30	20	20	20	30	20	20	20	30	20	20	20	300
Scenario 6	20	10	10	10	10	10	20	30	20	20	20	30	20	20	20	30	20	20	20	500

NOTES:

(1) In State 4, Zone B, DO levels reflected for Present and all scenarios are slightly lower that measured data in this zone in brackish periods (Figure 3.25). This was done to reflect the lower DO that occurs in the peripheral areas of this zone during this state (measurements were all taken in the main channel)

(2) Higher DIN concentrations in Zones A-C during State 5 (Scenario 6) reflects higher remineralisation that may be associated with biota dying as a result of hyper salinity (i.e. higher organic loading)

3.6.2 Reference vs. Present water quality

A summary of the average changes in key water quality parameters from reference to present in each zone in presented in Table 3.21.

Table 3.21. Summary of average changes in water quality from the Reference to Present State within each zone of the Klein estuary.

Parameter	Summary of change	Zone	Reference	Present
Salinity	Slight increase in salinity due to reduction in flow and related loss of State 4: Closed brackish	A (lower)	28	29
		B	28	29
		C	27	29
		D (river)	19	21
DIN (µg/ℓ)	Marked increase in nutrient input from anthropogenic sources (e.g. agriculture and WWTW effluent) from Reference to Present state	A (lower)	61	198
		B	50	191
		C	50	211
		D (river)	63	684
DIP (µg/ℓ)	Marked increase in nutrient input from anthropogenic sources (e.g. agriculture and WWTW effluent) from Reference to Present state	A (lower)	12	19
		B	10	18
		C	10	19
		D (river)	13	29
Turbidity (NTU)	No marked changes.	A (lower)	10	12
		B	10	12
		C	10	12
		D (river)	10	12
DO (µg/ℓ)	Increase in organic loading and nutrient input (causing eutrophication) from anthropogenic sources (e.g. agriculture and WWTW effluent) from Reference to Present state	A (lower)	7	5
		B	7	6
		C	7	5
		D (river)	6	4
Toxic substances	Agriculture in the catchment (herbicides and pesticides) and urban development along banks (metals and hydrocarbons) introduced some toxic substances into the estuary - assume 80% similarity to Reference.	80% similarity between Reference and Present		

3.6.3 Scoring present water quality

The similarity in each parameter (e.g. dissolved oxygen) to reference condition was scored as follows:

- Define **zones** along the length of the estuary **(Z)** (i.e. Zones A, B and C)
- **Volume fraction** of each zone **(V)** (i.e. A: Lower = 0.34; B: Middle = 0.33; C: Upper = 0.33)
- Different **abiotic states (S)** (i.e. States 1 to 5)
- Define the **flow scenarios** (i.e. Reference, Present, Future scenarios)
- Determine the **% occurrence** of abiotic states for each scenario
- Define **WQ concentration range (C)** (e.g. 6 mg/l; 4 mg/l; 2 mg/l)

Similarity between Present State, or any Future Scenarios, relative to the Reference Condition was calculated as follows:

- Calculate Average concentration for each Zone for Reference and Present/Future Scenarios, respectively:
- Average Conc (Z_A) = [({∑% occurrence of states in C_1}*C_1)+ ({∑% occurrence of states in C_2}*C_2)+({∑% occurrence of states in C_n}*C_n)] divided by 100
- Calculate similarity between Average Conc's Reference and Present/Future Scenario for each Zone using the Czekanowski's similarity index: ∑(min(ref,pres)/(∑ref + ∑pres)/2
- For the final scores, a weighted average of the similarity scores of different zones was computed using the volume fractions.

For the final scores, a weighted average of the similarity scores of different zones was computed using the volume fractions (Table 3.22).

Table 3.22 Summary of changes and calculation of the water quality health score

Variable		Summary of change	Score	% of impact non-flow related	Conf.
1	**Salinity**				
	Similarity in salinity	⇧ due to reduction in flow and related loss of State 4: Closed brackish	97	40	M/H
2	**General water quality in estuary**				
a	DIN and DIP concentrations	⇧⇧ due to nutrient enrichment from agriculture and WWTW discharges	56	90	M/L
b	Turbidity (transparency)	⇧ due to suspended solid loading from catchment (high flows) and WWTW (low flows)	92	90	M/L
c	Dissolved oxygen (mg/l)	⇩due to organic loading and eutrophication from catchment and WWTW	90	90	M/L
d	Toxic substances	⇧ anthropogenic (agriculture and urban) inputs	80	100	L
Water quality health score		$\boldsymbol{Score = (0.6 * S + 0.4 * (min\,(a\ to\ d))}$	**81**		
Adjusted score		Score excluding non-flow related effects		**98**	

3.7 Microalgae

There is very little data available for microalgae on the Klein estuary. Scott *et al.* (1952) refer to discoloration of the sand in parts of the estuary as a result of a large number of benthic microalgae. Grindley (1957, 1965) listed the following diatoms as being present in the system: *Triceratium, Skeletonema, Coscinodiscus, Rhizosolenia, Nitzschia*, *Bacillaria* and *Chaetoceros* (cited in De Decker 1989).

Chlorophyll data from 2012 (CSIR) shows that phytoplankton blooms (Chla concentration >20 µg/l) do occur. Compared to Reference conditions there is also possibly an increase in benthic microalgae biomass at sites of nutrient input e.g. septic tank leakage. Extensive agricultural activities in the catchment have increased inorganic nutrient loading in river inflow as has effluent discharge from the Stanford WWTW entering the system. Under present conditions nutrients are not limiting for microalgae growth and phytoplankton blooms could occur frequently depending on water retention time.

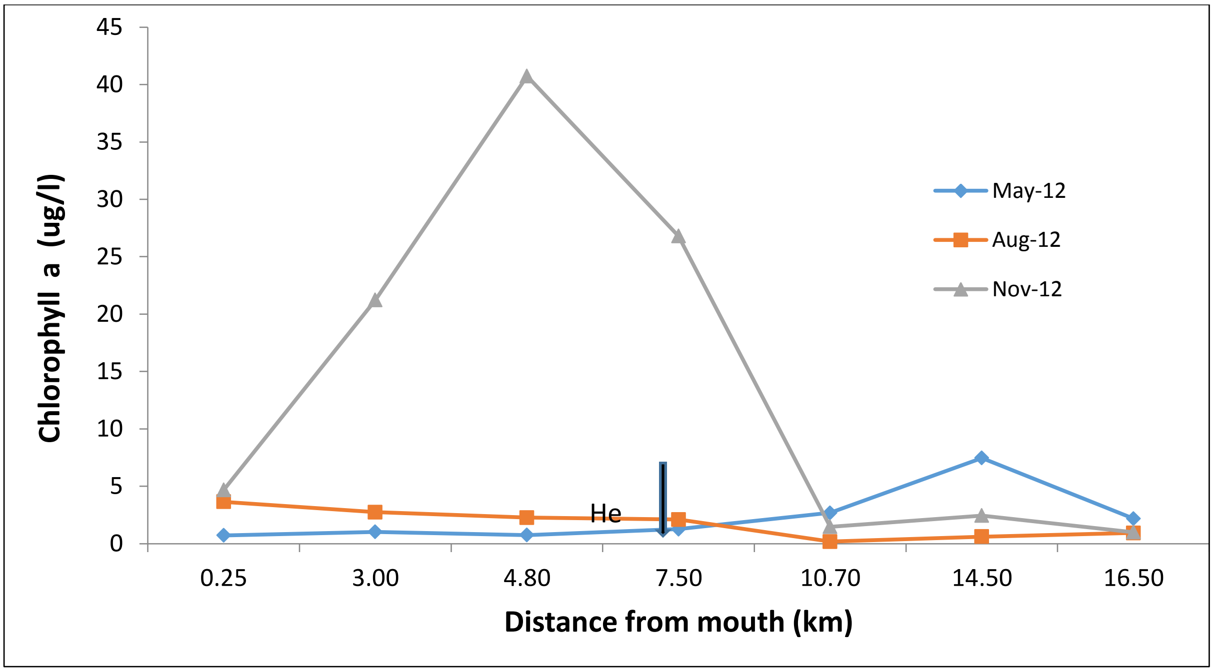


Figure 3.28. Chlororphyll a concentration in the Klein estuary on three occasions in 2012. (Data from CSIR).

3.7.1 Microalgae groups

Microalgae in the Klein estuary were divided into two groups – benthic microalgae and phytoplankton. Defining features for each group are listed in Table 3.23.

Table 3.23 Groups of microalgae considered in this study with their defining features.

Microalga groups	Defining features, typical/dominant species
Benthic microalgae	Benthic diatoms likely to be important in large shallow sand and mudflat area. Epiphytic communities would also be important on the emergent and submerged plants. MPB community generally consists of euglenophytes, cyanophytes and bacillariophytes (diatoms). Diatoms are generally dominant in the microphytobenthos. Loss of emergent or submerged macrophytes will represent a loss of epiphyte habitat.
Phytoplankton	There are indications of phytoplankton blooms (chlorophylla > 20 µg/l). There is likely to be competition for nutrients from macroalgae under closed mouth conditions. If coastal / estuarine lakes become eutrophic they change from one stable state to another i.e. clear water system with submerged macrophytes to a turbid, nutrient rich system with phytoplankton blooms. Flagellates, diatoms, dinoflagellates, cyanophytes, chlorophytes, euglenophytes and coccolithophorids are the dominant phytoplankton groups.

3.7.2 Baseline description

3.7.2.1 Description of factors influencing microalgae

The dominant factors that are considered to influence microalgae distribution and abundance are listed in Table 3.24.

Table 3.24 Effect of abiotic characteristics and processes, as well as other biotic components on microalgae groupings

	Phytoplankton					Benthic microalgae
	Cyanophytes	**Dinoflagellates**	**Chlorophytes**	**Diatoms**	**Flagellates**	
Temperature	Positive					
% Fines (<63 µm)	Positive					Positive
Salinity	Negative	Positive	Negative			
External P input	Positive (capable of fixing N)	Positive (if combined with N ⇧)	Positive (if combined with N ⇧)	Positive (if combined with N ⇧)	Positive (if combined with N ⇧)	Positive (if combined with N ⇧)
Grazing	Negative	Negative	Negative	Negative	Negative	
[O_2]	Positive	Negative	Negative	Negative	Negative	
Stratification		Positive				
External N input		Positive (if combined with P ⇧)	Positive (if combined with P ⇧)	Positive (if combined with P ⇧)	Positive (if combined with P ⇧)	Positive (if combined with P ⇧)
Turbidity	Negative	Negative	Negative	Negative	Negative	Negative
Organic content	Positive					Positive

3.7.3 Present vs. Reference conditions

Response of the various microalgae groups under the different abiotic states is summarized in Table 3.25 below and likely changes from Reference to Present day conditions are summarized in Table 3.26.

Table 3.25. Responses of microalgae groups under different abiotic states.

State	Name	Description
State 1	Open, marine	Intertidal benthic microalgae would expand under these conditions.
State 2	Open, gradient	Intertidal benthic microalgae would expand and different groups would be distributed along the salinity gradient.
State 3	Closed, marine	If turbidity is not limiting high subtidal benthic microalgae biomass is expected. Phytoplankton blooms could occur in the water column.
State 4	Closed, brackish	High subtidal benthic microalgae biomass in water less than 1 m depth. Phytoplankton blooms could occur.
State 5	Closed, hypersaline	Salt tolerant phytoplankton groups such as the cyanobacteria (blue/green algae) could bloom.

Table 3.26 Summary of relative changes from reference to present condition.

KEY DRIVERS	CHANGE
⇩ river flow ⇧ mouth closure	⇧ Phytoplankton and benthic microalgae biomass due to greater water retention time.
⇩intertidal habitat due to development & disturbance	⇩Habitat for intertidal benthic microalgae.
⇧ nutrient enrichment	⇧ Phytoplankton and benthic microalgae biomass. Possibility of nuisance toxic species that will outcompete other species.
TOTAL CHANGE	⇧microalgae biomass, ⇩species richness

3.7.4 Health of the microalgae component

Similarity scores for microalgae under the Present condition relative to the Reference condition is summarised in Table 3.27.

Table 3.27. Similarity scores of microalgae in the Present condition relative to the Reference condition.

VARIABLE	SUMMARY OF CHANGE	SCORE	CONF
Phytoplankton			
a. Species richness	There could have been a loss of pollution intolerant species and those species associated with the open marine phase.	75	L
b. Abundance	Low base flow and increase in closed mouth conditions together with high nutrient inputs has increased water column chlorophyll-a (phytoplankton biomass) particularly in the upper reaches (Zone D).	65	M
c. Community composition	Blue-green algae would outcompete other algal groups under nutrient rich, brackish conditions.	70	M
Benthic microalgae			
a. Species richness	There could have been a loss of pollution intolerant species and those benthic species associated with the intertidal habitat.	75	L
b. Abundance	The increase in mouth closure and more stable sediment conditions would increase BMA biomass in the shallow sheltered areas of the estuary. Biomass may be high at sites of point source nutrient input. Bank stabilisation and loss of intertidal habitat would represent a loss of habitat for benthic microalgae.	65	M
c. Community composition	Blue-green algae would outcompete other algal groups under nutrient rich, freshwater conditions. The reduction in river flow and floods would result in the deposition of fines and organic material causing a shift from episammic (sand) to epipelic (mud) benthic microalgae communities.	70	M
Microalgae health score min (a to c)		**65**	**M**
% of impact non-flow related impacts		50	
Adjusted score		83	

3.8 Macrophytes

3.8.1 Main groups and baseline description

The distribution of different habitats within the estuarine functional zone (5 m topographical contour) was mapped from the 2014 aerial images obtained from National Geo-Spatial Information (Surveys and Mapping). Previous mapping efforts including De Decker's (1989) vegetation map of the lower reaches (Figure 3.29) and the 2006 vegetation map produced in the field by Dr T. Bornman as part of the C.A.P.E. estuaries programme (Turpie and Clark 2007) (Figure 3.30). Change in macrophyte habitat from the Reference conditions was determined through visual comparison with the earliest aerial images (1938 and 1980) as well as comparison of area to the 2006 map.

In 2014 (Figure 3.31), the Klein Estuary had a large open water channel comprising roughly half of the estuarine functional zone. During open mouth conditions, the estuary would have drained increasing the available habitat of sand/mud banks and rocky outcrops. Saltpans would have developed in low lying areas in the middle reaches. Salt marsh was abundant on the southern banks but less so on the northern bank as this bank was steeper and less suitable for establishment. *Salicornia meyeriana* was limited to a small patch south of the estuary mouth. Reeds and sedges, mainly the common reed, *Phragmites australis,* fringed the middle and upper reaches of the estuary where salinity was suitable for establishment. Common reed was also abundant at the Klein river inlet. A number of epiphytic microalgae and submerged macrophyte species also inhabited the estuary. These species are restricted to fringing areas where the water depth did not exceed 1.5 m.

Veldkornet (2013) sampled across the salt marsh and terrestrial habitats in the Klein estuary and found 28 species occurring in seven different habitats. Two of these species *Cotula filifolia* Thunb. and *Limonium scabrum* (L.f.) Kuntze are endemic to South Africa (National Red Data list - Van Niekerk and Turpie, 2011). De Decker (1989) reported *Cotula myriophylloides* which is classified by the IUCN red list to be 'Critically Endangered' and likely already extinct. The Klein Estuary may still provide a refuge for these species.

Some of the floodplain (34 ha) within the estuarine functional zone has been lost to agriculture and housing developments. This would have removed salt marsh as well as reed and sedge habitat. An additional 110 ha was in a disturbed state due to encroaching development, artificial mouth breaching and invasive plants. Natural floodplain consisted of shrubland described by De Decker (1989) as Strandveld shrubland and grass. Species conspicuous in the shrubland included *Metalasia muricata, Euclea racemosa, Searsia glauca, Pterocelastrus tricuspidatus, Olea exasperata, Chrysanthemoides monilifera and Psoralea fruticans*. According to De Decker (1989) the Klein River and its tributaries were heavily invaded with alien wattles (*Acacia saligna*, *A. longifolia* and *A. mearnsii*). De Decker (1989) commented that river bank vegetation was often removed by grain farmers to prevent the roosting and nesting of seed eating birds. This caused localised destruction and bank erosion.

Comparison of the current 2014 vegetation map with the 2006 vegetation map produced by Dr T. Bornman as part of C.A.P.E. estuaries program (Turpie & Clark 2007) revealed little change in the distribution of macrophyte habitats.

Summary data on the extent a distribution of different macrophyte habitats in the Klein Estuary is presented in Table 3.28.

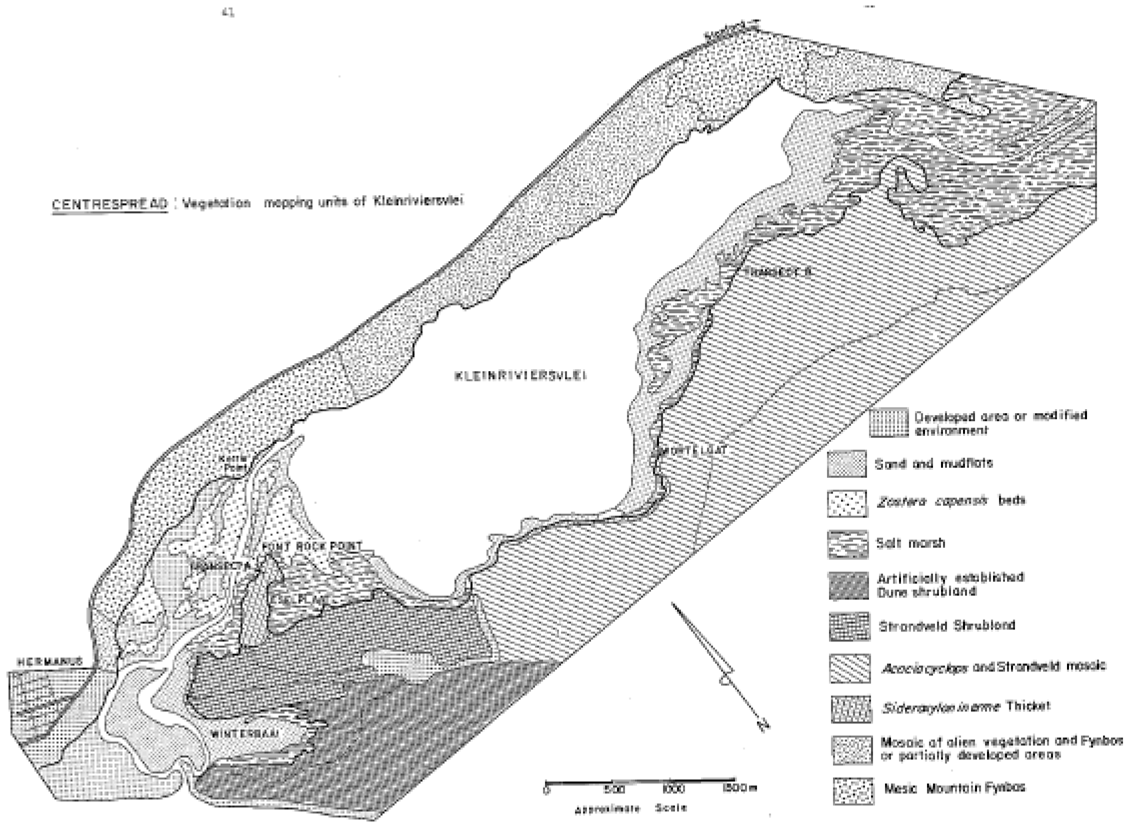


Figure 3.29 Vegetation map of the lower reaches of the Klein Estuary (from De Decker 1989).

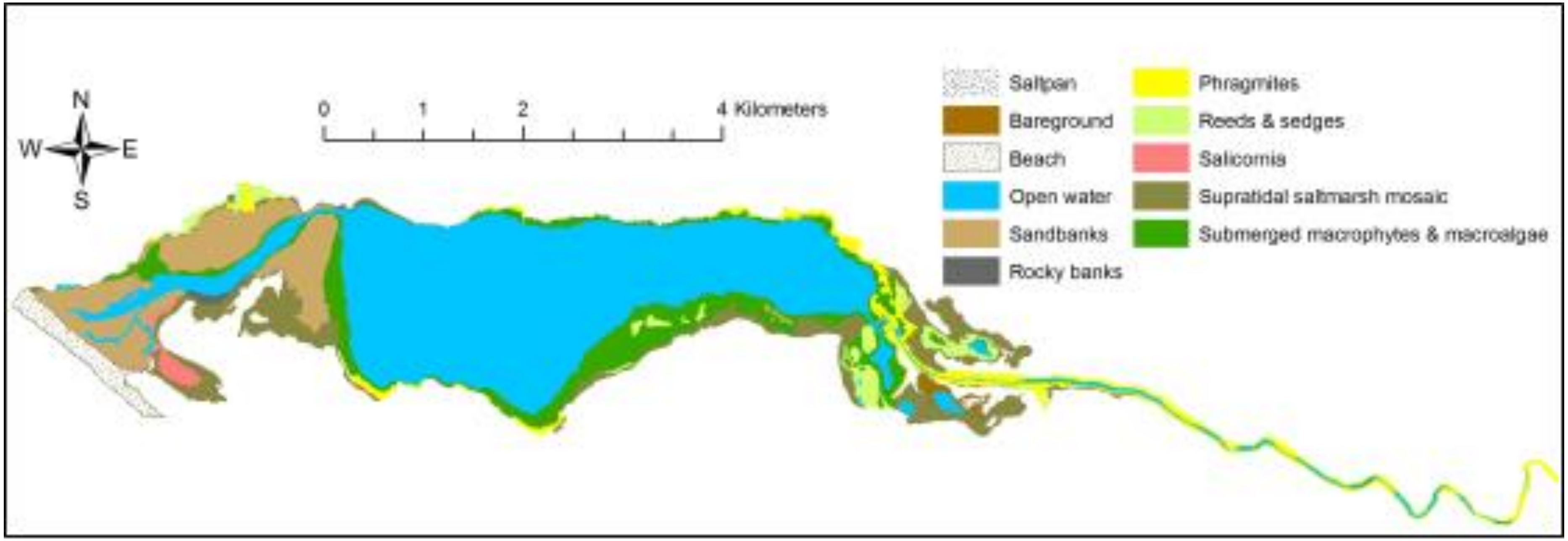


Figure 3.30 Macrophyte habitats of the Klein Estuary 2006 (Turpie and Clark 2007).

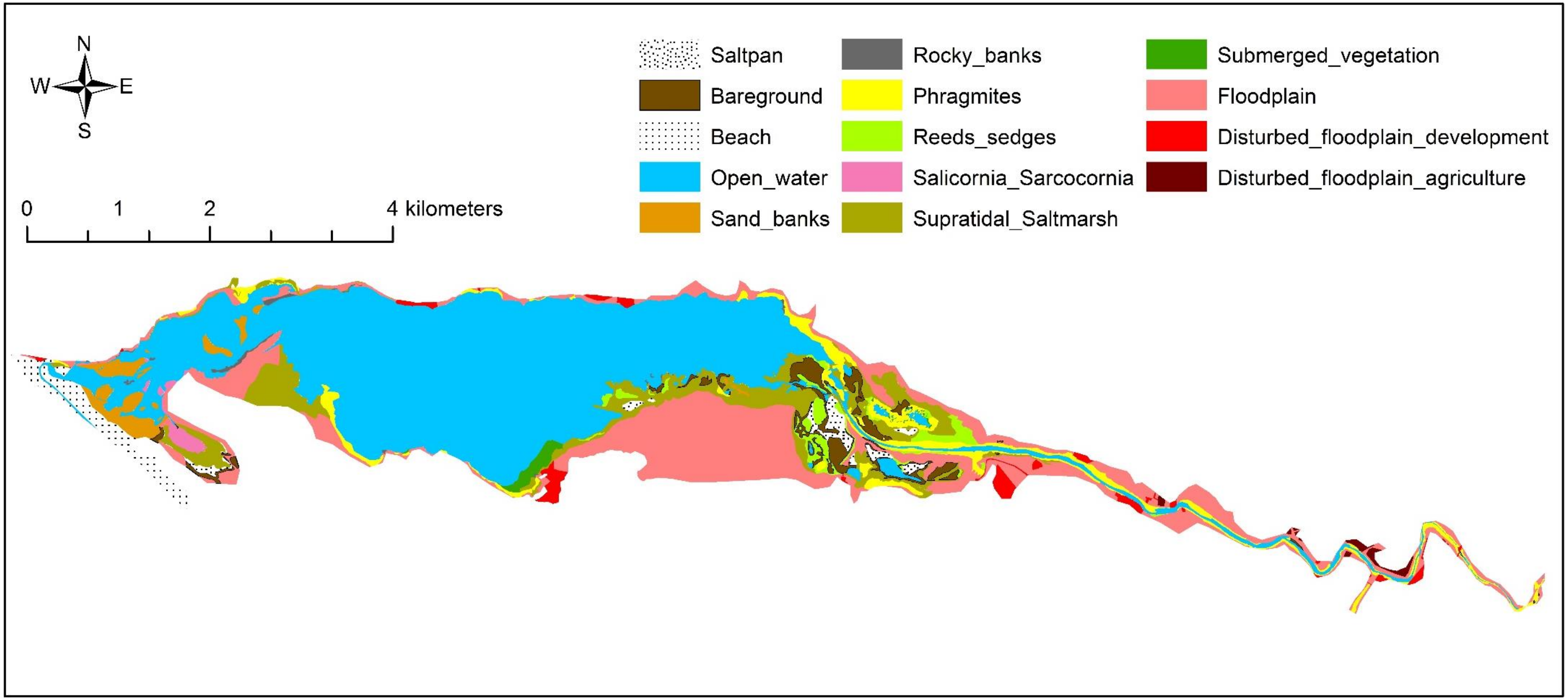


Figure 3.31 Macrophyte habitats of the Klein Estuary mapped from 2014 aerial imagery.

Table 3.28 Summary of estuarine habitat area in the Klein Estuary.

HABITAT TYPE	DEFINING FEATURES, TYPICAL/DOMINANT SPECIES	AREA (HA IN 2014)
Open surface water area	Serves as a possible habitat for phytoplankton.	741.6
Sand and mud banks	Intertidal zone consists of sand/mud banks that are regularly flooded by freshwater inflows. This habitat provides a possible area for microphytobenthos to inhabit. Saltpans located in the middle reaches of the estuary were Included in this habitat type.	79
Macroalgae	Marine algae*, Ectocarpus fasciculatus, Polysiphonia* sp., *Porphyra capensis* and *Ulva capensis* appear to be restricted to the rocky fringes on the southern bank in the mouth region.	Not visible Estimated 92
Submerged macrophytes	*Ruppia maritima, Stuckenia pectinata* and *Zostera capensis* are abundant in the shallow open water areas fringing the deeper channel. Although not clearly visible from aerial photographs the estimated cover is based on mapping from Turpie & Clark (2007). According to De Decker (1989) *Ruppia* favours the shallow, less saline areas of the middle and upper reaches, while *Zostera* occurs in the deeper more saline water of the middle and lower reaches near the mouth.	11 mapped Estimated 92
Salt marsh	Intertidal species include *Sarcocornia natalensis*, *Salicornia meyeriana, Cotula coronopifolia, Cotula filifolia, Triglochin bulbosum* and *Paspalum vaginatum*. *Limonium scabrum, Sporobolus virginicus, Plantago carnosa* and *Samolus porosus* were found in the upper intertidal zone whereas *Sarcocornia pillansii*, *Stenotaphrum secundatum* and *Opreum frutescens* were the dominant supratidal species.	170
Reeds and sedges	The following species have been recorded, and belong to the families Cyperaceae, Juncaceae & Poaceae: *Bolboschoenus maritimus*, *Cyperus laevigatus*, *Juncus acutus, J. kraussi, Phragmites australis* and *Schoenoeplectus triqueter.*	127
Floodplain	Agriculture and development has removed estuarine habitat from the estuarine functional zone. The remainder of the floodplain mapped in 2014 was a mixture of shrubland and grassy areas.	35 (transformed) 110 (disturbed) 280 (mostly intact)

3.8.2 Factors influencing macrophyte distribution and abundance

Key responses of estuarine macrophytes to changes in abiotic and other biotic components are summarised in Table 3.29, while Table 3.30 translates these into expected responses under each of the abiotic states.

Table 3.29 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various macrophyte groupings

PROCESS	MACROPHYTES
Mouth condition	Open mouth conditions create intertidal habitat for salt marsh and reeds and sedges. Artificial breaching and fluctuating water levels would decrease submerged macrophyte biomass and extent.
Flow velocities (e.g. tidal velocities or river inflow velocities)	Strong tidal flows could limit the establishment of submerged macrophytes.
Total volume and/or estimated volume of different salinity ranges	The longitudinal salinity gradient promotes species richness, different macrophyte habitats are distributed along the length of the estuary. For example, salt marsh in the lower reaches and reeds and sedges in the upper reaches.
Floods	Large floods are important in flushing out salts from the salt marsh area. Hypersaline sediments caused by evaporation and infrequent flooding will result in dry bare patches in the supratidal salt marsh areas. Floods also prevent sedimentation and reed encroachment in the upper reaches.
Salinity	Base flow is needed to maintain longitudinal salinity gradients from the mouth to head of the estuary which increases macrophyte diversity.
Turbidity	Increased sediment load within the water column results in a reduction in the photic zone and will limit submerged macrophyte establishment and distribution.
Dissolved oxygen	The estuary is mostly well oxygenated, but increased incidences of eutrophication due to inputs from anthropogenic sources will lower DO concentrations.
Nutrients	Increased nutrient inputs would increase macrophyte growth particularly in areas of freshwater seepage. This would cause macroalgae blooms as well as reed and sedge growth.
Sediment characteristics (including sedimentation)	Increased sedimentation at the mouth of the estuary due to artificial breaching at low levels has affected the ability of the estuary to naturally flush out sediment. Sedimentation of the upper reaches will encourage growth of reeds and sedges.
Other biotic components	Invasive plants occur in the riparian zone.

Table 3.30. Summary of macrophyte responses to different abiotic states

State	Name	Responses
State 1	Open, marine	Persistent conditions would cause die-back of reeds and sedges in the middle reaches (salinity of 20 for greater than 3 months). Favourable for salt marsh growth.
State 2	Open, gradient	Favours salt marsh growth. Reeds may increase in the less saline upper reaches.
State 3	Closed, marine	Salt marsh will expand when water level is low (<1.6 m MSL) and submerged macrophytes will expand in cover when water level is high.
State 4	Closed, brackish	Die-back of salt marsh and reeds and sedges due to inundation and high water level (>1.6 m MSL). Submerged macrophytes expand but restricted to shallower areas. Anthropogenic nutrient inputs presently encourage macroalgae growth.
State 5	Closed, hypersaline	Die-back of macrophyte habitats, particularly reeds and sedges as salinity is now between 40 to 75 ppt. Salinity will exceed the tolerance range of most macrophytes. Salt pans will develop and result in bare ground unsuitable for growth. Highly saline soils may limit the growth of salt marsh species. Low water level (<1 m MSL) will result in a smaller area available for submerged macrophytes.

3.8.3 Reference condition

A summary of the relative changes in macrophytes in the Klein Estuary from Reference to Present is presented in Table 3.31.

Table 3.31 Summary of relative changes from Reference condition to Present state

KEY DRIVERS	CHANGE
⇩ river flow ⇧ salinity	⇩ Reed & sedge growth in upper reaches ⇩ Salt marsh due to salinization and formation of bare areas.
⇧ mouth breaching and ⇩ State 4: closed brackish	⇩ Submerged macrophytes which need stable closed mouth conditions and high water level
⇧ agriculture, disturbance & invasive plants	⇩ Macrophyte habitats and disturbance of floodplain habitat
⇧ nutrient enrichment	⇧ Macroalgae blooms
TOTAL CHANGE	⇩ Reed & sedge ⇩ Salt marsh ⇩ Submerged macrophytes ⇧Macroalgae

3.8.4 Macrophyte health

The health of the macrophytes was assessed in terms of species richness, abundance and community composition. Change in species richness was measured as the loss in the average species richness expected during a sampling event, excluding species thought to not have occurred under Reference condition (Table 3.32). Abundance was measured as the change in cover of macrophyte habitats from Reference to Present according to the following formula:

% similarity = 100*present area cover / reference area cover.

In total, the macrophytes, excluding macroalgae, covered 1025 ha under Reference conditions and now cover 826 ha. Floodplain agriculture and development has removed 35 ha and disturbed some of the natural floodplain which occupies 390 ha. Invasive plants occupy approximately 10 ha of estuarine habitat.

The distribution and abundance of salt marsh habitat has remained similar to Bornman's (2006) vegetation map of the Klein Estuary. Some open water has also developed into saltpans since 2006. This could create more barren bare ground thus reducing habitat available for salt marsh. Visual comparison of aerial photographs from 1938 and 1980 suggest a similar macrophyte distribution to present, with the steeper north bank being sparsely vegetated and salt marsh dominant in the lower reaches on the south bank. Under natural conditions the Klein Estuary would have received more river inflow and therefore experienced slightly lower salinity and more open mouth conditions. The water column would have been less turbid which would have favoured submerged macrophyte growth and zonation along the length of the estuary. Nutrient enrichment currently favours the increase of macroalgae that will shade and outcompete submerged macrophytes. Calm sheltered conditions during the closed mouth phase would also favour macroalgae growth, usually filamentous green algae. Although not mapped from aerial photographs invasive species may have displaced indigenous vegetation in the floodplain.

Change in community composition was assessed using a similarity index which is based on estimates of the area cover of each macrophyte habitat in the reference and present state. (Czekanowski's similarity index: ∑(min(ref,pres) / (∑ref + ∑pres)/2)). The macrophytes are thus 87% similar to what they were under reference conditions.

Table 3.32 Area covered by macrophyte habitats and calculation of the similarity in community composition for the Klein Estuary

MACROPHYTE HABITAT	REFERENCE AREA COVER (ha)	PRESENT AREA COVER (ha)	MINIMUM
Salt marsh	220	169.7	169.7
Reeds & sedges	180	127.4	127.4
Submerged macrophytes	190	139	139
Macroalgae	40	92	40
Invasive plants	0	10	0
Floodplain	425	280 (disturbed 110 ha not included)	280
% similarity	**Sum min / (sum ref + present) /2**	**756 / (818 + 1055)**	81

The macrophyte health score for the present state is presented in

Table 3.33.

Table 3.33 Present macrophyte health score, as well as an estimate of the change associated with non-flow related factors and an adjusted score only reflecting flow related effects

VARIABLE	SUMMARY OF CHANGE	SCORE	CONF
1. Species richness	Low baseflow and increase in salinity has reduced macrophyte species richness. Development, disturbance and invasive species will result in a loss of species. A critically endangered species *Cotula myriophyllodes* may have been lost from the estuary.	80	M
2. Abundance	Some macrophyte habitat (35 ha) lost due to development, agriculture and invasive species. Large floodplain area (110 ha) is disturbed. Nutrient enrichment has encouraged growth of macroalgae which would decrease the area covered by submerged macrophytes due to shading. Increase in salinity and development of saltpans would reduce density and cover of salt marsh plants.	70	M
3. Community composition	Salt marsh has declined due to increased salinity producing dry barren areas. Reeds and sedges have declined since reference conditions due to reduced freshwater inflow. Species composition may be affected by the presence of invasive species.	81	M
Macrophyte health score (min 1-3)		**70**	
% of impact non-flow related		20	
Adjusted score		79	

3.9 Invertebrates

3.9.1 Baseline description and current state of the estuary

Very little research has been undertaken on the invertebrate communities of the Klein estuary and almost no quantitative data exists for this group. Scott *et al*. (1952) provided a qualitative account of the invertebrate fauna of the estuary and included a species list of taxa present at the time. A total of 45 soft-bottom invertebrate macrofauna species were recorded in this study. Taxa recorded are listed in Table 3.34 where each species has been assigned to a trophic functional group, and categorised into major functional groups.

In order to better understand the Present day condition of the soft-bottom benthic invertebrate community, a field survey was conducted on 11 March 2015 at the same localities sampled by Scott *et al.* (1952) - Figure 3.32. Soft-bottom macrofauna at each sites were sampled using a van Veen grab with a bite size of approximately 200 cm^2. Five grabs and a separate sediment sample were collected at each of the sampling sites (Figure 3.33) except for sites KR3, KR4 and KR5 which could not be sampled in time available. Grab samples were pooled and sieved in a 1 mm mesh bag to remove fine sediment. Macrofauna were extracted and stored in plastic bottles and fixed with 100% ethanol. In the laboratory samples were rinsed and, where necessary, stained with Rose Bengal to aid identification. Macrofauna were identified to species level where possible, but at least to family level in all instances. Sediment samples were analysed for grain size and percentage total organic carbon (TOC).

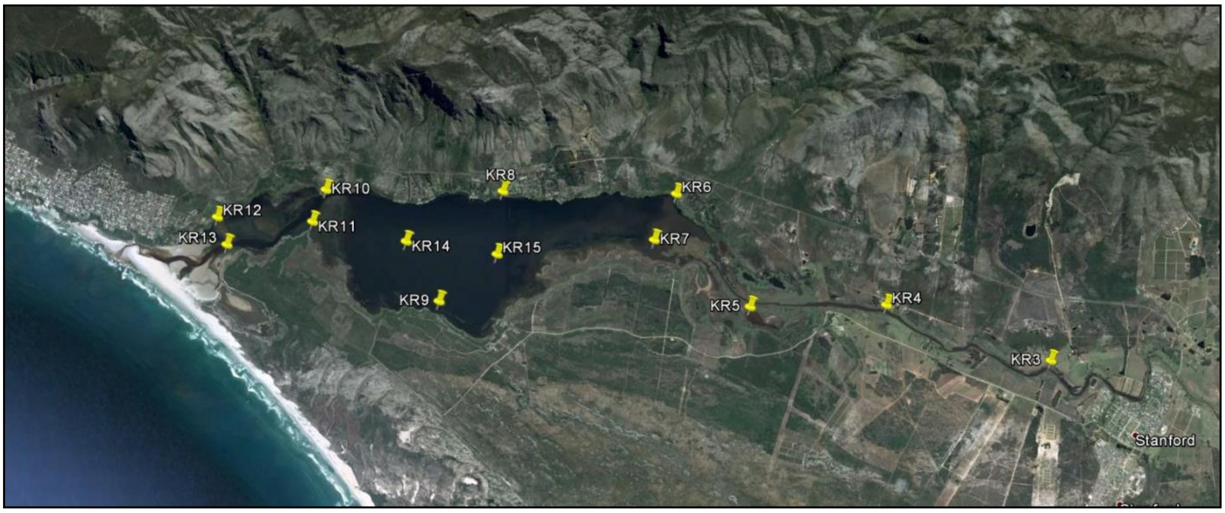


Figure 3.32. Sampling sites as per Scott et al. (1952) – image source: Google Earth.

It should be noted that the methods used for sample collection in this particular study differ from those used by Scott *et al.* (1952) and this should be taken into account when comparing the findings of the two studies. Due to time constraints, hard substrata and the water column were not sampled during the March 2015 field survey. It is recommended that invertebrates inhabiting hard substrata and the water column itself are included in future studies.

Table 3.34. Soft bottom macrofauna species recorded in the Klein estuary by Scott *et al.* (1952) – those highlighted in blue were also recorded during the March 2015 survey.

Species	Category*	Taxon	Trophic functional group
Americorophium triaeonyx	3	Amphipoda	Filter feeder
Ceradocus rubromaculatus	3	Amphipoda	Detritivore
Eorchestia rectipalma	3	Amphipoda	Detritivore
Grandidierella lutosa	3	Amphipoda	Detritivore
Melita zeylanica	3	Amphipoda	Detritivore
Paramoera capensis	3	Amphipoda	Detritivore
Siphonoecetes sp	3	Amphipoda	Detritivore
Talorchestia ancheidos	3	Amphipoda	Detritivore
Talorchestia australis	3	Amphipoda	Scavenger
Arcuatula capensis	8	Bivalvia	Filter feeder
Chlamys sp.	9	Bivalvia	Filter feeder
Donax serra	9	Bivalvia	Filter feeder
Pisiduim sp.	8	Bivalvia	Filter feeder
Solen capensis	9	Bivalvia	Filter feeder
Tivela sp.	9	Bivalvia	Filter feeder
Cyclograpsus punctatus	11	Brachyura	Scavenger
Hymenosoma orbiculare	11	Brachyura	Predator
Ovalipes trimaculatus	11	Decapoda	Predator
Palaemon peringueyi	12	Decapoda	Scavenger
Aplysia spp	7	Gastropoda	Grazer
Aplysina capensis	7	Gastropoda	Grazer
Assiminea sp.	6	Gastropoda	Grazer
Bullia sp.	5	Gastropoda	Scavenger
Bursatella leachii	7	Gastropoda	Grazer
Haminoea alfredensis	7	Gastropoda	Grazer
Corallana Africana	4	Isopoda	Detritivore
Cyathura carinata	4	Isopoda	Detritivore
Deto echinata	4	Isopoda	Scavenger
Exosphaeroma hylecoetes	4	Isopoda	Detritivore
Pseudosphaeroma barnardi	4	Isopoda	Detritivore
Stymphalus dilatatus	4	Isopoda	Scavenger
Turbellarians	22	Platyhelminthes	Predator
Arenicola loveni	2	Polychaeta	Detritivore
Capitella capitata	1	Polychaeta	Detritivore
Ceratonereis keiskama	1	Polychaeta	Detritivore
Neanthes willeyi	2	Polychaeta	Predator
Nepthys sp.	2	Polychaeta	Detritivore
Platynereis dumerilii	2	Polychaeta	Predator
Prionospio malmgreni	1	Polychaeta	Detritivore
Pseudofabriciola capensis	1	Polychaeta	Detritivore
Scoletoma fragilis	2	Polychaeta	Detritivore
Sipunculoidea	21	Sipunculoidea	Filter feeder
Leptochelia savignyi	3	Tanaidacea	Detritivore/predator
Tanais philetarus	3	Tanaidacea	Detritivore/predator
Callichirus kraussi	17	Thalassinidea	Detritivore

*Classified in accordance with the criteria listed in Table 3.38.

According to Scott et al. (1952), the Klein estuary consists of four regions – the river; the canal-like stretch (KR3 – KR4); the ford at the head of the lagoon (KR5 – KR6) and the lagoon itself (KR7 – KR13), which constitutes the majority of available estuarine habitat. The "river" and "canal-like stretch" are both included in what is referred to as "Zone D" in this study (see Section 3.3.1), while the "ford at the3 head of the lagoon" corresponds more of less with Zone C for this study, and "the lagoon itself" has been split into Zone A (the mouth region) and Zone B (the vlei). At the time of their survey, saline influences reportedly only penetrated a short distance up the canal-like stretch (max. salinity 7.9), and it was only from the ford at the head of the lagoon where higher salinities (up to 19.7) were detected (Scott *et al.* 1952). A brief description of the state of the system and its invertebrate communities taken from Scott *et al*.'s (1952) report is presented below.

Scott *et al.* (1952) reported that high seasonal variability was observed in the canal-like stretch of the estuary (sites KR3-KR4, Zone D) - the water level ranges from about 1 m deep and 400 m wide during winter, to barely a trickle between barren, wind-swept sand-banks in the summer months (Scott *et al*. 1952). This was considered to have a significant impact on the soft-bottom benthic invertebrate community structure both in terms of abundance, diversity and biomass. The lagoon reportedly also experienced fluctuations in seasonal conditions but these are not to any great extent reflected in the fauna, apart from the animals which are dependent on the sea. The abundance, diversity and biomass of such marine organisms were largely influenced by the extent of the tide when the mouth of the estuary was open.

Figure 3.33. Grab sampling at site KR7, looking west.

A wide variety of fauna reportedly existed throughout the various habitats which make up the lagoon. Along the high-water mark on the shores of the lagoon there exists a mass of decaying weed. While this remained wet, it constituted a large source of food for many invertebrates including insects and their larvae, isopods and amphipods. This habitat was considered unique in that it attracted both terrestrial and marine fauna (mostly found in water logged sand and mud just above the water-line).

From time to time, depending on the physical conditions present, the rocky outcrops towards the lower reaches of the lagoon (in the region of KR10, KR11 and KR12) were reportedly inhabited by marine species typical of an intertidal rocky shore community (Table 3.35 – Scott *et al*. 1952). Such species are found on the water line and are obviously tolerant to low salinity but rarely survive the flooding of freshwater during the winter months. On occasion *Oxystele spp., Siphonaria sp.* and *Littorina knynaensis* persisted over the winter as well.

Table 3.35. Hard-substratum (rocky shore) species recorded at rocky outcrops in the Klein Estuary after Scott et al. (1952).

Species	Category*	Taxon	Trophic functional group
Lima sp.	9	Bivalvia	Filter feeder
Mytilus galloprovincialis	9	Bivalvia	Filter feeder
Ostrea margaritacea	9	Bivalvia	Filter feeder
Striostrea prismatica	9	Bivalvia	Filter feeder
Acanthochitona garnoti	7	Chitonida	Grazer
Amphibalanus amphitrite	20	Cirripedia	Filter feeder
Balanus trigonus	20	Cirripedia	Filter feeder
Chthamalus dentatus	20	Cirripedia	Filter feeder
Afrolittorina knysnaensis	7	Gastropoda	Grazer
Diodora sp.	5	Gastropoda	Detritivore
Helcion pruinosus	5	Gastropoda	Grazer
Oxystele tigrina	5	Gastropoda	Grazer
Oxystele variegata	5	Gastropoda	Grazer
Siphonaria capensis	5	Gastropoda	Grazer
Siphonaria oculus	5	Gastropoda	Grazer
Siphonaria serrata	*5*	Gastropoda	Grazer
Tectonatica tecta	6	Gastropoda	Predator
Lepidonotus clava	2	Polychaeta	Predator
Lysidice natalensis	2	Polychaeta	Detritivore
Perinereis falsovariegata	2	Polychaeta	Predator
Scololepis squamata	2	Polychaeta	Detritivore
Sipunculoidea	21	Sipunculoidea	Filter feeder
Leptochelia savignyi	3	Tanaidacea	Detritivore/predator
Tanais philetarus	3	Tanaidacea	Detritivore/predator
Callichirus kraussi	17	Thalassinidea	Detritivore

*Classified in accordance with the criteria listed in Table 3.38.

The seagrass and weed beds of *Zostera* and *Ruppia* were densely populated with small animals such as amphipods *Melita zeylanica*, *Americorophium triaeonyx* and isopods *Exosphaeroma sp.* The distribution of all of these species was highly variable; appearing some times in high numbers and other times not at all. These organisms were found throughout the lagoon and no obvious factors were seen to influence their variations in abundance.

The soft bottom habitat in the lagoon reportedly consisted of sand with varying amounts of overlying mud (Scott *et al.* 1952). In general, the lower reaches of estuaries usually have sandy bottoms and are more saline, whereas the higher reaches are characterised by finer sediment and are less saline (Day 1951). Teske & Wooldridge (2003) have shown that the nature of sediment particle size is more important than salinity in limiting the distribution of macrobenthos within several South African estuaries. Results from the analysis of sediment samples collected and analysed as part of this study (Table 3.36) show that the sediment sampled throughout the lagoon consists mostly of sand with small amounts of mud (≤5%) and gravel (≤3%) i.e. very little difference in sediment composition was noted among the sites sampled. This is reflected in the distribution of the fauna throughout the system: the tanaid, *Leptochelia savignyi*; isopod, *Cyathura estuaria*; and amphipod, *Melita zeylanica* were present at least at seven of the study sites (Table 3.37). In comparison to the results of Scott *et al.* (1952), the ubiquitous distribution and common occurrence of these species throughout the system remains largely unchanged after more than 60 years.

Table 3.36. Physical parameters and results from sediment sample analyses recorded during the March 2015 survey.

Site	Salinity (ppt)	Temperature (deg C)	depth (m)	Mean particle size	Gravel	Sand	Mud	Description	% TOC
KR6	33.6	23.4	0	159.9	0%	99%	1%	Fine Sand	1.46
KR7	36.2	22.4	0	266.3	1%	94%	5%	Fine Sand	4.28
KR8	31.8	22.6	2	421.7	0%	98%	2%	Medium Sand	2.44
KR9			1.2	259.7	0%	99%	0%	Fine Sand	1.16
KR10			1	256.9	1%	95%	3%	Fine Sand	10.04
KR11			0	474.9	3%	93%	4%	Medium Sand	10.73
KR12			0	211.4	0%	97%	3%	Fine Sand	5.25
KR13			0	290.0	0%	100%	0%	Fine Sand	3.10
KR14			4	546.5	2%	94%	4%	Medium Sand	16.12
KR15			3	271.5	0%	98%	2%	Fine Sand	2.90

Figure 3.34 shows the total abundance and biomass of the benthic macrofauna classified into higher order taxonomic groups. Although there is no quantitative data available, Scott *et al.* (1952), mention that the sand prawn, *Callichirus kraussi* (Thalassinidea), "occurred frequently in very large numbers, both below the water line and where the sand is water-logged above it" and that "in the upper reaches its numbers fall off fairly rapidly and it is not very common, though present at the ford at the head of the lagoon". From Figure 3.34 it is clear that this is no longer the case and a significant decline in both abundance and biomass of *C. kraussi* (Thalassinidea) may have occurred since the 1940's (although this may in part reflect the fact that the grab that was used to collect samples in this study probably does not sample to the same depth as the "bucket and spade" used by Scott *et al* 1952).

Table 3.37. Soft-bottom benthic invertebrate species and their abundance (per m^2) collected at each site during the March 2015 survey – species highlighted in red have not been recorded before.

Species	KR6	KR7	KR8	KR9	KR10	KR11	KR12	KR13	KR14	KR15
Capitella capitata	0	0	0	0	70	0	670	40	0	0
Ceratonereis keiskama	300	20	0	380	0	0	0	10	0	10
Prionospio malmgreni	0	0	0	0	10	0	0	40	0	0
Scolelepis squamata	0	0	0	0	10	0	0	0	0	0
Cyathuria estuaria	430	170	70	240	90	0		120	30	60
Exosphaeroma truncatitelson	10	60	0	0	0	0	0	0	0	0
Melita zeylanica	30	780	50	0	660	0	100	50	30	10
Americorophium triaeonyx	820	30	0	60	0	0	0	0	0	0
Leptochelia savignyi	140	340	90	0	260	0	0	20	620	1960
Callichirus kraussi	0	0	40	1000	0	0	0	150	0	20
Insect larva A	0	0	0	0	0	0	40	0	0	0
Insect larva B	0	0	0	0	0	0	10	0	0	0
Insect larva C	0	0	0	0	0	0	10	0	0	0
Insect larva D	0	0	0	0	10	0	50	0	0	0

It is likely that the cumulative impact of bait collection and the other anthropogenic activities in conjunction with natural change in physical conditions could explain this decline and also perhaps that of the blood worm, *Arenicola loveni*. As an ecosystem engineer, largely through bioturbation of sediments and habitat creation for commensal burrow-dwelling taxa, the reduction in abundance and biomass of *C. kraussi* is likely to have an impact on the soft-bottom benthic invertebrate community structure. Since there are no quantitative baseline data available it is not possible to determine how severe this impact may be.

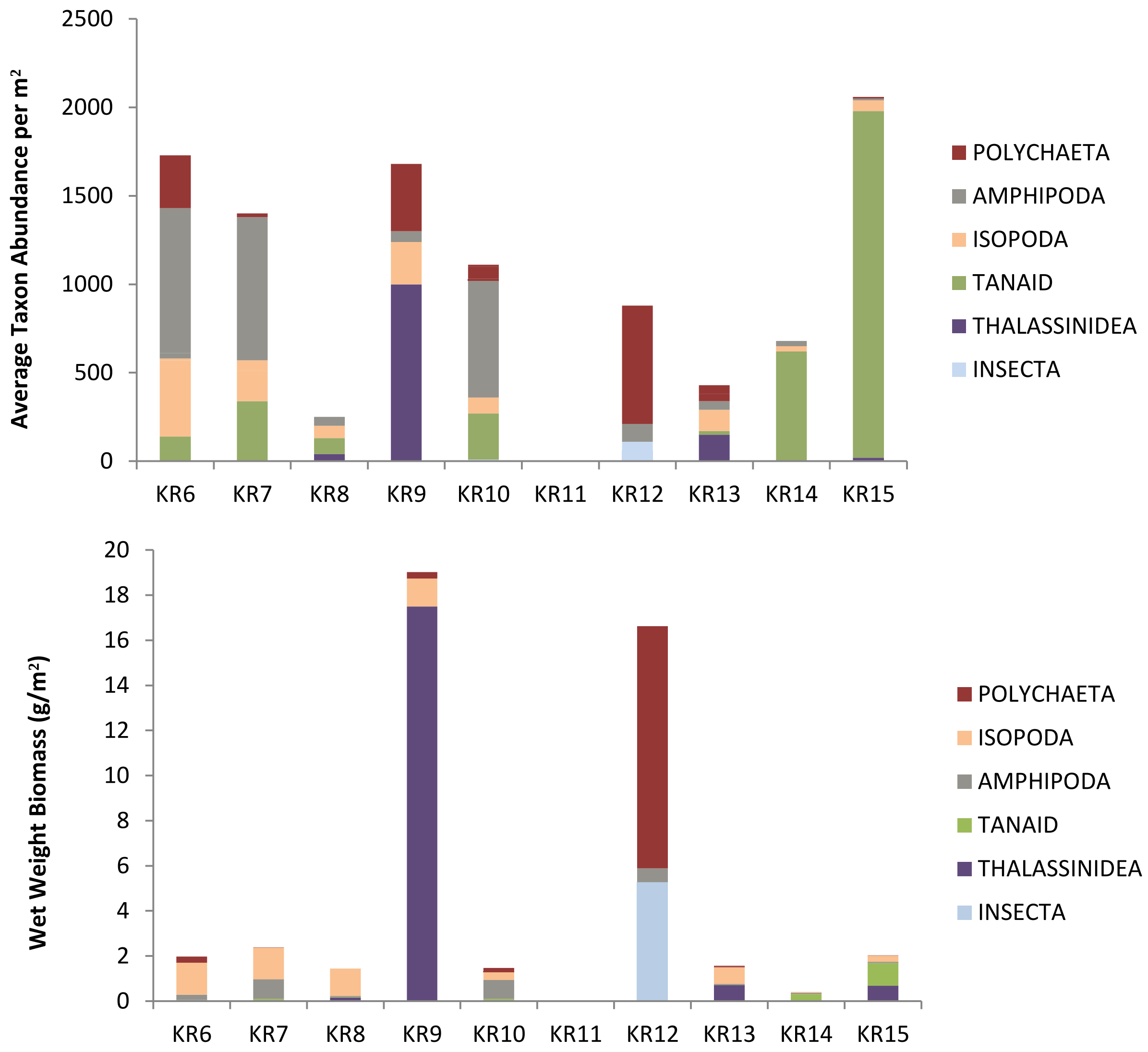


Figure 3.34. Total abundance (top) and biomass (bottom) of soft-bottom benthic invertebrate macrofauna sampled in the Klein Estuary in March 2015. The fauna have been placed in higher order taxonomic groups.

3.9.2 Invertebrate groups

Each invertebrate species associated with estuaries utilises and depends on a particular suite of biotic and abiotic parameters which determine their relative abundance and distribution throughout the system. In order to predict a response in the invertebrate community structure to changes in these parameters, the estuarine invertebrate macrofauna need to be classified according to their relative dependence on these parameters. The classification used in this study is shown in Table 3.38 where the parameters influencing each category are shown along with a summary of responses of the various invertebrate groups to abiotic and biotic drivers.

Table 3.38. Classification of South African estuarine invertebrate fauna and the parameters influencing their abundance and distribution. POM = particulate organic matter, MPB = Microphytobenthos

#	Description	Influencing factors
1	Polychaetes - estuarine resident (e.g. *Ceratoneries keiskamma*)	Medium to fine sediments; detritus; prey
2	Polychaetes - marine (e.g. *Arenicola*)	Med to coarse sediments; detritus; open mouth; saline water
3	Amphipods and Tanaids	Finer sand/mud; shelter; detritus; POM; reduced salinity
4	Isopods	Coarse sediments; higher salinity; dead matter
5	Gastropods - marine dominated species (grazers, detritivores, scavengers & predators e.g. *Bullia*)	Detritus; open mouth; MPB; higher salinity
6	Gastropods - resident sediment living grazers, detritivores & predators (e.g. *Hydrobia*; *Natica*)	Shelter from wave action; submerged macrophytes; MPB; detritus
7	Gastropods - grazers associated with macrophytes	Shelter from wave action; submerged macrophytes; MPB
8	Bivalves - estuarine resident	Med-fine sediments; submerged macrophytes; POM
9	Bivalves - marine (e.g. *Donax*/*Tellina*)	Med-coarse sediments; open mouth; POM
10	Crabs - resident estuarine (e.g. *Spiroplax)*	Med-fine sediments; (presence of prawns for *Spiroplax*)
11	Crabs - marine (e.g. *Hymenosoma*)	Open mouth; saline
12	Carids - marine (e.g. *Palaemon*)	Med-fine sediments; detritus; open mouth; high salinity
13	Carids - resident (e.g. *Betaeus*)	Med-fine sediments; detritus; submerged macrophytes; prawns (*Betaeus*)
14	Saltmarsh inverts	Saltmarsh
15	Insect larvae	Lower salinities
16	Mudprawns (e.g. *Upogebia*)	Fine sand/mud; open mouth; POM
17	Sandprawns (e.g. *Callianassa*)	Sand; not extended fresh water (>17ppt to breed); POM
18	Zooplankton - marine	Phytoplankton; open mouth
19	Zooplankton – estuarine resident	Phytoplankton
20	Cirripedia - filter feeding marine and brak-water dominated species (e.g. *Amphitrite; Chthamalus*)	Open mouth; saline; suspended POM
21	Sipunculida - marine	Detritus; open mouth; higher salinity
22	Platyhelminthes	Open mouth; saline; small invertebrates

3.9.3 Factors affecting the invertebrate fauna

Responses of the different invertebrate groups found in the Klein River Estuary to the main abiotic drivers are summarised in Table 3.39.

Table 3.39. Effect of abiotic characteristics and processes, as well as other biotic components on invertebrate groupings

Factor	Affected categories
Mouth condition (provide temporal implications where applicable)	Closed mouth leads to decrease in species richness (absence of marine associated species). Open mouth linked to increased salinity values and opportunity for euryhaline species (category 2, 4, 5, 9, 11, 12, 13, 16, 17, 18) to increase in biomass and abundance if salinity increases from a low base (<10). An open mouth is also important for the input of larvae into the estuary from the marine environment for recruitment and vice versa.
Retention times of water masses	An increase in retention times of water masses will increase the abundance of macroalgae which, in turn, leads to a decrease in abundance of intertidal invertebrate macrofauna (observed in April survey). Furthermore, increased retention times would favour estuarine resident subtidal macrofauna tolerant of reduced salinity (category 1, 3, 6, 7, 8, 15, 19).
Flow velocities (e.g. tidal velocities or river inflow velocities)	Increased flow velocities would scour and flush the system of fine sediment leaving a greater proportion of coarse sediment towards the lower reaches which is less preferential to burrowing species – essentially most of the species recorded in this study. Phytoplankton levels would decrease in response to high flow velocities, thereby limiting the amount of food available to zooplankton.
Total volume and/or estimated volume of different salinity ranges	A change in total volume or estimated volume of different salinity ranges would result in a corresponding change in habitat accessible to the invertebrate macrofauna, particularly if the mesohaline area increases (salinity values above 17-20 particularly benefits categories 16 and 17). Associated species would respond accordingly – i.e. marine dominated species would increase with a greater marine volume component and estuarine resident species would retreat to the upper reaches, where there is less habitat available and vice versa.
Floods	A severe flood would scour the system, flushing most benthic invertebrate macrofauna out to sea and inundating the system with a high sediment load. Therefore an initial decrease in abundance of all invertebrates would be expected followed by a steady increase as the fauna recovers and exploits the newly available nutrients, detritus and particulate organic matter.
Salinities	A decrease in salinity would have a greater negative impact on invertebrates within the lower reaches of the Klein River Estuary which are adapted to life in a tidal system. However, categories 1, 3, 4, 8 and 19 have a wide salinity range and are able to tolerate low salinity values (<10) but abundances would be affected by the duration of low salinity regimes. If salinity falls too low breeding ceases until conditions become more favourable again. Because the system is periodically tidal, higher salinities would favour most species which occur there.
Turbidity	Little to no effect on benthic forms
Dissolved oxygen	Oxygen levels below ~50% surface saturation will have a negative effect on populations of zooplankton (category 18, 19). Oxygen levels below ~50% surface saturation will have a negative effect on populations of all other invertebrate species, however, the polychaete *Capitella capitata* (category 1) will tolerate extremely low values. Category 8 and 9 are able to withstand temporary periods of hypoxia.
Subtidal, intertidal and supratidal habitat	Different benthic invertebrate macrofauna show differening affinities for intertidal and subtidal habitats and changes in the availability of these two habitat types will influence the relative abundance of these taxa. No benthic invertebrate macrofauna have been recorded in the supratidal habitat of the Klein River Estuary.

Factor	Affected categories
Sediment characteristics (including sedimentation)	Species composition likely to change if particle size composition of sediments changes. Open mouth states favour upstream intrusion of marine sandy sediment which favours sand-dwellers. The dominant species *Callichirus kraussi* (category 17) requires a sandy substrate and this generally occurs in the lower third of the estuary. On the other hand, Tanaids (category 3) require finer muddier substrata, therefore changes to sediment type will limit abundance and distribution of these categories. Increased sedimentation would temporarily smother subtidal and intertidal habitats.
Phytoplankton biomass	An increase in phytoplankton would result in an increase in zooplankton (categories 18 and 19).
Benthic micro-algae biomass	Increased benthic microalgal biomass will favour burrowing forms such as categories 3 and 4.
Zooplankton biomass	During closed mouth phase zooplankton biomass will be low. Subsequent increases in biomass will coincide with open mouth phases which favour tidal exchange enabling marine species to enter the estuary. Since zooplankton rely on water column for movement, tidal intrusion will enhance colonisation of upper sites, Salinity increases upstream will also favour euryhaline species.
Aquatic macrophyte cover	*Callichirus kraussi* abundance and biomass will decrease and favour other species such as *Exosphaeroma, Cyathura estuaria* and *Talorchestia* who all favour vegetated areas. Generally, a major shift in the overall estuary community structure. Highly detrimental in extreme cases to all intertidal benthic invertebrate macrofauna – macroalgae cover results in hypoxic conditions in the underlying sediment resulting in mass mortality.
Fish biomass	Increased predation on invertebrates if fish biomass increases

3.9.4 Reference condition

A total of 45 soft-bottom invertebrate macrofauna species were recorded during the Scott *et al*. (1952) study versus 14 (four of which are insect larvae and are not strictly marine/estuarine) in the March 2015 study. It must be noted that the results presented in the Scott *et al.* (1952) study are from many days of field work over three years in comparison to a single day's field work in March 2015. Furthermore, different sampling techniques were used for the two studies. Therefore, such a reduction in alpha diversity is a by no means an indication that the system has undergone change and is most certainly a result of the differences in sampling effort and methodology mentioned above. The most significant change in the soft-bottom invertebrate macrofaunal community structure from the reference condition would be the observed decline in both abundance and biomass of *C. Kraussi, A. loveni* and *Solen capensis*, all of which colonise the lower reaches of the estuary and are popular bait species. Such changes are likely to be a result of the combined effects of excess sedimentation, compaction of sand in the lower reaches from motor vehicles and bait collection (CSIR, 1989). The current health status of the invertebrate component of the Klein River Estuary has not significantly deteriorated in comparison to the reference condition. Due the lack of quantitative data, the level of confidence associated with this conclusion is low.

3.9.5 Health of the invertebrate component

Health scores for the invertebrate component are provided in Table 3.40. Similarity scores of Invertebrates in the Present condition relative to the Reference condition.Table 3.40.

Table 3.40. Similarity scores of Invertebrates in the Present condition relative to the Reference condition.

Variable	Change from natural	Score	Confidence
1. Species richness	Possible loss of a few stenohaline marine species from mouth region, however, overall diversity remains high with little change from the Reference state (species which prefer increased macrophyte growth on floodplain will proliferate e.g. *Exosphaeroma, Cyathura estuaria* and *Talorchestia* who all favour vegetated areas).	80	M
2. Abundance	Little change from Reference. Possible reduction in abundance of stenohaline marine species and estuary-dependent marine species. Small taxa (amphipods, isopods and tanaids) resident in weed beds and remain abundant.	75	L
3. Biomass		70	L
4. Community composition	Decreased abundance and biomass of large burrowing species result in a significant shift in the overall estuary community structure.	70	M
Invertebrate score (min 1-3)		**70**	**M**
Degree to which deviation from natural is due to non-flow related impacts		20	
Adjusted score		77	

3.10 Fish

3.10.1 Fish groups

Estuaries provide an extremely important habitat for fish in southern Africa. The vast majority of coastal habitat in southern Africa is directly exposed to the open ocean, and as such is subject to intensive wave action throughout the year (Field & Griffiths 1991). Estuaries in southern Africa are thus disproportionately important relative to other parts of the world, in that they constitute the bulk of the sheltered, shallow water inshore habitat in the region. Juveniles of many marine fish species in southern Africa have adapted to take advantage of this situation, and have developed the necessary adaptations to enable them to persist in estuaries for at least part of their life cycles. There are at least 100 species that show a clear association with estuaries in South Africa (Whitfield 1998). Most of these are juveniles of marine species that enter estuaries as juveniles, remain there for a year or more before returning to the marine environment as adults or sub-adults where they spawn, completing the cycles. Several other species also use estuaries in southern Africa, including some that are able to complete their entire life cycles in these systems, and a range of salt tolerant freshwater species and euryhaline marine species. Whitfield (1994) has developed a detailed classification system of estuary associated fishes in southern Africa. He recognized five major categories of estuary associated fish species and several subcategories (Table 3.41).

Table 3.41. Classification of South African fish fauna according to their dependence on estuaries (Whitfield 1994)

Category	Description
I Ia Ib	Truly estuarine species, which breed in southern African estuaries; subdivided as follows: Resident species which have not been recorded breeding in the freshwater or marine environment Resident species which have marine or freshwater breeding populations
II IIa IIb IIc	Euryhaline marine species which usually breed at sea with the juveniles showing varying degrees of dependence on southern African estuaries; subdivided as follows: a. Juveniles dependant of estuaries as nursery areas b. Juveniles occur mainly in estuaries, but are also found at sea c. Juveniles occur in estuaries but are more abundant at sea
III	Marine species which occur in estuaries in small numbers but are not dependant on these systems
IV	Euryhaline freshwater species that can penetrate estuaries depending on salinity tolerance. Includes some species which may breed in both freshwater and estuarine systems. Includes the following subcategories: a. Indigenous b. Translocated from within southern Africa c. Alien
V	Obligate catadromous species which use estuaries as transit routes between the marine and freshwater environments

Fish species in categories I, II, and V as defined by Whitfield (1994) are all wholly or largely dependent on estuaries for their survival and are hence the most important from an estuary conservation perspective. These species need to receive most attention from a management perspective.

3.10.2 Baseline description

3.10.2.1 Community composition

A total of 51 fish species from 27 families have been recorded from the Klein Estuary (Table 3.42). Including all Category Ia, Ib, IIa & Va species, 23 (45%) of these are entirely dependent on estuaries to complete their lifecycle. Ten of these breed in estuaries and include the estuarine round-herring *Gilchristella aestuaria*, Bot River klipvis *Clinus spatulatus*, Cape halfbeak *Hyporhamphus capensis*, Cape silverside *Atherina breviceps*, Knysna sand-goby *Psammogobius knysnaensis*, four *Caffrogobius* species, Cape halfbeak *Hyporhamphus capensis* and pipefish *Syngnathus temminckii*. Nine, including dusky kob *Argyrosomus japonicus*, white steenbras *Lithognathus lithognathus*, leervis *Lichia amia*, Cape moony *Monodactylus falciformis*, flathead mullet *Mugil cephalus*, freshwater mullet *Myxus capensis* and Cape stumpnose *Rhabdosargus holubi*, are dependent on estuaries as nursery areas for at least their first year of life. A further three, namely the catadromous African mottled eel *Anguilla bengalensis*, Madagascan mottled eel *A. marmorata* and longfin eel *A. mossambica* require estuaries as transit routes between the marine and freshwater environment. In addition, *Mugil cephalus* and *Myxus capensis* may be regarded as facultative catadromous species (Whitfield 1994).

Another 10 (20%) species e.g. harder *Liza richardsonii*, groovy mullet *Liza dumerilii*, elf *Pomatomus saltatrix* and white stumpnose *Rhabdosargus globiceps* are at least partially dependent on estuaries. In all, 65% of can be regarded as either partially or completely dependent on estuaries for their survival.

Eleven of the remaining species are marine species e.g. piggy *Pomadasys olivaceum* and wildeperd *Diplodus hottentotus*, which occur in, but are not dependent on estuaries; while seven, the indigenous Cape galaxias *Galaxias zebratus* and Cape kurper *Sandelia capensis* and introduced carp *Cyprinus carpio*, largemouth *M. salmoides*, smallmouth *M.dolomieu* and spotted bass *M. punctatus*, Mozambique tilapia *Oreochromis mossambicus* and banded tilapia *T. sparrmanii* are alien euryhaline freshwater species whose penetration into estuaries is determined by salinity tolerance.

In many respects, the composition of the Klein Estuary fish assemblage is identical to that of the Bot Estuary. Species that breed in estuaries and/or estuarine residents make up 20% of the Klein and Bot Estuary fish fauna as compared to 26-27 % for the permanently open Berg and Olifants estuaries on the West Coast and between 4-18 % for all estuaries on the southwest (Cape Agulhas to Cape Point), east and KwaZulu-Natal coasts (Bennett 1994, Lamberth *et al*. 2008). Species that are entirely dependent on estuaries comprise 45% of the Klein Estuary fish fauna versus 46% for the Bot, a figure which is slightly lower than the 54% for all south-coast estuaries, but high compared to 26, 25, 22 and 9% for west, southwest, east and KwaZulu-Natal coasts respectively (Bennett 1994, Lamberth & Whitfield 1997, Harrison 1999). Partially estuarine dependent species comprise 20% of the Klein and Bot fish fauna, which is lower than the 29-40% for the west coast but within the 27-18% range for southwest, east and KwaZulu-Natal coast estuaries (Bennett 1994, Lamberth *et al*. 2008). Non estuary-dependent marine species comprise a relatively low proportion (20%) of the fish species recorded in the Klein, and most, e.g. gurnard *Chelidonichthys capensis* and smooth houndshark *Mustelus mustelus,* can be construed as rare vagrants which seldom enter estuaries. Their occurrence in the temporarily open/closed Klein is largely a function of their chance proximity to the mouth when it was open.

Based on their distributional ranges given by Smith and Heemstra (1986), 26 (51%) of the fish recorded in the Klein Estuary are southern African endemics including the Botriver klipvis *Clinus spatulatus* which has an extremely limited range being confined to the Klein and Bot Estuaries. In terms of the fish importance score outlined in the RDM methodology, the Klein Estuary has a biodiversity and overall importance score of 95.3% which places it within the top quintile of all estuaries in South Africa (Taljaard *et al*. 1999, Turpie *et al.* 2002). The Klein Estuary is a relatively large temporarily open/closed system 1 154 ha and accounts for about 12% of the total estuarine fish nursery area from False Bay to Port Alfred. Its importance lies in its size and its situation in a region of high endemicity within the warm temperate, cool temperate transition zone.

3.10.2.2 Abundance

Gillnet sampling is usually targeted at the adults and sub-adults of the larger fish species whereas seine-nets are aimed at catching juveniles and the smaller fish species. A total of 232 222 fish representing 31 species from 16 families were caught in 269 seine hauls in the Klein Estuary from 2000 to 2015. A further 3 730 fish representing 18 species from 11 families were caught in 68 (7 X 30 m panels1) gillnet sets during the same period. Numerically, the seine catches at 863 $fish.haul^{-1}$ compare poorly with those in the Bot at 1 918 $fish.haul^{-1}$ over the same time period. Gillnet catches were not significantly different with 55 $fish.set^{-1}$ versus 58 $fish.set^{-1}$ in the Klein and Bot respectively. Estuarine resident breeders *Atherina breviceps* (46%) and *G.aestuaria* (28%) dominated seine catches numerically followed by *Liza richardsonii* (10%) and *Psammogobius knysnaensis* (8%) that were also important. Of the remainder, only *C. spatulatus*, *Caffrogobius* and *S. temminckii* contributed more than 1% to the total catch. Gillnet catches of large estuary-dependent fish e.g. *L. lithognathus* were very low or absent e.g. *A. japonicus* probably slightly due to more prolonged mouth closure but most likely due to high illegal gillnet effort in the present day. Relatively low gillnet catches of adult Mugillidae in the estuary are also indicative of high gillnet effort.

There has also been a substantial increase in the number of freshwater fish mostly due to the introduction of alien species and to lower salinities arising from prolonged periods of mouth closure. Despite this, the fish assemblage of the Klein is very similar to the Bot and typical of that of temporarily open/closed estuaries, being dominated numerically by estuary-breeders and subject to highly variable recruitment by estuary-dependent marine species. This said, survival of the latter has been severely compromised by illegal netting and, despite some years of good recruitment, their contribution to the fish assemblage remains low. Overall, reduced recruitment, alien fish and illegal netting have reduced abundance to about 60% of reference, a figure that would be lower were it not for the buffering of the numerically dominant estuary breeders.

3.10.2.3 Seasonality

Resident estuary-breeders, whether they are livebearers (e.g. *C. spatulatus*) or release eggs, (e.g. *G. aestuaria*), reproduce throughout the year with peaks in the spring and summer. Breeding also tends to be concentrated in the dry season to prevent eggs and larvae from being flushed out to sea. Flushing may also be countered by spawning at the head of the estuary and in the freshwater reaches (e.g. *G. aestuaria*) or by producing adhesive eggs (e.g. *A. breviceps*). Estuary-residence and year-round breeding maintains a fairly constant biomass and availability to piscivorous predators throughout the year. The peak spawning and recruitment period for obligate estuary-dependent marine species (e.g. *L. lithognathus*) is spring to early summer and, under natural conditions, coincides with higher flow and mouth-opening in the Klein, Bot and other estuaries in the southwestern Cape. Partially estuary-dependent fish (e.g. *L. richardsonii*), peak in early summer but will recruit opportunistically throughout the year through overwash events. If breaching occurs, adults leaving the system may become reproductively active and contribute to another spawning peak in the sea in late summer.

Catadromous (glass) eels enter the Klein (and other systems) mainly in summer, at night on high spring tides, under strong river flow and when the mouth is open. It is not known whether recruitment of the three eel species is synchronous or varies according to their spawning localities, times and duration of larval stages in the pelagic environment. Upstream migration of elvers is enhanced by high flow and inundated marginal areas. Adult return migration to the sea (8-20 years later) is cued and facilitated by floods and high flow. Physiological and morphological changes in migrating adults silver eels mean that migration is irreversible once it commences, even if conditions deteriorate.

3.10.2.4 Connectivity with other estuaries and the marine environment

The Klein, together with the Bot, account for 25-30% of the available estuarine fish nursery-area from Cape Point to Port Alfred. It is crucial that at least one of these two estuaries is open to the sea during the spring/early summer recruitment window each year. With the exception of some drought years, the Klein usually opened annually under natural conditions. In the past decade, however, drought, wastewater spills and eutrophication have seen that system and its fish under severe stress from hypoxia and high water temperatures, with mass mortalities occurring. The Bot, which has opened during this time period, would have provided some level of mitigation by allowing recruitment of juvenile fish and larvae and the export of adult fish to recruit into the marine fisheries. The latter function was probably negated by the high illicit gillnet catches in both the Klein and Bot estuaries, however.

Connectivity between the Klein and Bot is highlighted by the fact that *Clinus spatulatus* only occurs in these two systems and nowhere else. On the other hand, the *G. aestuaria* population in the Bot is probably the most genetically isolated of this species along the entire South African coastline (Norton 2005). This can be at least partly explained by its life-history characteristics but also by the fact that fish recruitment into Walker Bay and its estuaries is limited compared to other bays in South Africa, mostly due to its relative isolation and currents bypassing the bay, deflecting further out to sea. This may also be a factor in the recruitment of estuary-dependent marine species, as it may limit the estuary recruitment window more than elsewhere along this country's coastline. Connectivity between these two estuaries occurs during regional flood events usually coinciding with cutoff-lows when both systems are open and connected via their fluvial plumes (von der Heyden *et al.* 2015, Figure 3.35).

Figure 3.35. Satelitte image taken during flood conditions showing linkage between the Bot and Klein estuaries. Source: Lamont (2014)

Table 3.42. A list of all species (51) recorded in the Klein River Estuary. The species are arranged according to family (27) and the five major categories of estuarine-dependence as suggested by Whitfield 1994. * *Anguilla bengalensis* & *A. marmorata* assumed to occur with *A. mossambica* in the catchment.

Family name	Species name	Common name	Dependence category
OSTEICHTHYES			
Anabantidae	*Sandelia capensis*	Cape kurper	IV
Anguillidae	*Anguilla bengalensis*	African mottled eel*	Va
	Anguilla marmorata	Madagascar mottled eel*	Va
	Anguilla mossambica	Longfin eel	Va
Ariidae	*Galeichthyes feliceps*	Barbel	IIb
Atherinidae	*Atherina breviceps*	Cape silverside	Ib
Carangidae	*Lichia amia*	Leervis	IIa
Centrarchidae	*Lepomis macrochirus*	Bluegill sunfish	IV
	Micropterus punctatus	Spotted bass	IV
	Micropterus dolomieu	Smallmouth bass	IV
	Micropterus salmoides	Largemouth bass	IV
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	IV

	Tilapia sparrmanii	Banded tilapia	IV
Clinidae	*Clinus spatulatus*	Bot River klipvis	Ib
Clupeidae	*Gilchristella aestuaria*	Estuarine roundherring	Ia
Elopidae	*Elops machnata*	Ladyfish	IIa
Galaxiidae	*Galaxias zebratus*	Cape galaxias	IV
Gobiidae	*Caffrogobius gilchristi*	Prison goby	Ib
	Caffrogobius natalensis	Baldy	Ib
	Caffrogobius nudiceps	Barehead goby	Ib
	Caffrogobius saldanha	Commafin goby	Ib
	Psammogobius knysnaensis	Knysna sand-goby	Ia/Ib
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	IIa
	Pomadasys olivaceum	Piggy	III
Hemiramphidae	*Hemiramphus far*	Spotted halfbeak	IIc
	Hyporhamphus capensis	Cape halfbeak	Ib
Lobotidae	*Lobotes surinamensis*	Tripletail	III
Monodactylidae	*Monodactylus falciformis*	Cape moony	IIa
Mugilidae	*Liza dumerilii*	Groovy mullet	IIb
	Liza richardsonii	Harder	IIc
	Liza tricuspidens	Striped mullet	IIb
	Mugil cephalus	Springer mullet	IIa/Vb
	Myxus capensis	Freshwater mullet	IIa/Vb
Ophiichthidae	*Ophisurus serpens*	Sand snake-eel	III
Pomatomidae	*Pomatomus saltatrix*	Elf	IIc
Sciaenidae	*Argyrosomus japonicus*	Dusky kob	IIa
	Atractoscion aequidens	Geelbek	III
Soleidae	*Heteromycteris capensis*	Cape sole	IIb
	Solea turbynei	Blackhand sole	IIb
Sparidae	*Diplodus hottentotus*	Wildeperd / zebra	III
	Diplodus capensis	Blacktail / dassie	IIc
	Lithognathus lithognathus	White steenbras	IIa
	Rhabdosargus globiceps	White stumpnose	IIc
	Rhabdosargus holubi	Cape Stumpnose	IIa
	Sarpa salpa	Strepie	III
	Spondyliosoma emarginatum	Steentjie	III
Syngnathidae	*Syngnathus temminckii*	Pipefish	Ib
Tetraodontidae	*Amblyrhynchotes honckenii*	Blaasop	III
Triglidae	*Chelidonichthys capensis*	Cape gurnard	III
OSTEICHTHYES			
Triakidae	*Mustelus mustelus*	Smooth houndshark	III
Rhinobatidae	*Acroteriobatus annulatus*	Lesser sandshark /guitarfish	III

3.10.3 Factors affecting the fish community

Abiotic characteristics and processes affecting various groups of fish in the Klein estuary are summarised in Table 3.43.

Table 3.43. Effect of abiotic characteristics and processes, as well as other biotic components on fish groupings.

Fish	Ia. Estuarine residents (breed only in estuaries)	Ib. Estuarine residents (breed in estuaries and the sea)	IIa. Estuary dependent marine species	IIb and c. Estuary associated species	III. Marine migrants	IV. Euryhaline freshwater species
Mouth condition	Prolonged periods of mouth closure see *G. aestuaria* and *C. spatulatus* spread throughout the system. During mouth opening *G. aestuaria* migrates to the head of the estuary and freshwater reaches to avoid being swept out to sea. *C. spatulatus* escapes to the marginal areas but which often results in stranding, high mortalities & population crashes of 90% or more. Prolonged mouth closure and stability sees *G. aestuaria* outcompeted by *A. breviceps.*	Many of these fish are flushed during mouth opening. Gobies escape to and get trapped in the marginal weed whereas some may find refuge in *Callianassa* burrows. *A. breviceps* is less able to switch feeding mode than *G.aestuaria* and is outcompeted during mouth opening	Crucial that mouth open during the peak spring/early summer juvenile recruitment window for these obligate estuary-dependent species.	Mouth needs to be open during the peak spring/early summer juvenile recruitment window but these species can also recruit to, and survive in, the surf-zone. Mouth opening during early summer also allows adult *L. richardsonii* to return to the sea, become reproductively active and contribute to a second spawning peak in late summer. Some can recruit via overwash / swash from the sea.	Presence in the estuary a function of frequency and duration of mouth opening and their chance proximity to the mouth when opening occurs. Overall, little impact on populations but may provide a refuge from adverse conditions in the sea (e.g. hypoxia, thermal stress) when they occur. Klein depauperate w.r.t. these species.	Prolonged periods of mouth closure can allow the salt tolerant *O. mossambicus* to spread throughout the estuary where the sandy substratum is ideal for the building and defending of nets. Territorial behaviour and aggressive defence of nests and females may exclude other species of fish of similar size. As a partial control measure, eggs, larvae and juveniles of this and other introduced species can be flushed from the system during breaching.
Retention times of water masses	*G. aestuaria* & *A. breviceps* change feeding modes (selective vs filter) dependent on the availability of phytoplankton & zooplankton.		Juveniles of all of these species feed primarily on zooplankton and then small benthic invertebrates which fluctuate according to retention time.			Insect larvae food biomass & availability increases with retention time
Flow velocities (e.g. tidal velocities or river inflow velocities)	Resident species *G. aestuaria* moves further upstream in response to higher flow. *C. spatulatus* moves to the marginal areas.	Juveniles of all of these species make use of flow heterogeneity to migrate into the estuary during opening. High velocities create many standing waves, counter-currents and eddies that can be used to swim into the estuary against the flow. Most recruitment is likely to occur this way. Egg dispersal is passive, as is larval to some extent but larvae will migrate vertically into the desired direction of flow. All these fish exploit tidal currents when feeding and following the tidal 'front' up the estuary. Eddies accumulate food and provide refugia for both adult and juvenile fish				High flow velocities may disrupt nesting and flush some introduced fish.
Total volume and/or estimated volume of different salinity ranges	Higher volumes means more available habitat, especially for fish that spend most of their time in the mid-water. Also provides refuge from piscivorous predators. Brackish water habitat is good for resident and estuary associated marine migrants while marine water is good for marine species. This said, fish in the Klein and other temporarily open/closed estuaries are confined to the system for most of the time and distributed according to salinity tolerance whereas those in permanently open ones are distributed according to salinity preference. This said, most estuary fish tolerant of low (associated with high volumes) rather than high salinities (associated with low volumes). High water levels that inundate supratidal areas are positive for juvenile marine fish and small estuarine species.					High volumes & dilution allow establishment of invasive fish.
Floods	*G. aestuaria* moves	Juvenile fish in the system will find refuge in the			Either move	Indigenous fish move

Fish	Ia. Estuarine residents (breed only in estuaries)	Ib. Estuarine residents (breed in estuaries and the sea)	IIa. Estuary dependent marine species	IIb and c. Estuary associated species	III. Marine migrants	IV. Euryhaline freshwater species
	further upstream in response to floods. *C. spatulatus* moves to the marginal areas. Connectivity to adjacent estuaries (Bot) relies on flood events, especially those occurring regionally.	marginal areas during floods. Freshwater loving species e.g. *M. falciformis* will use the opportunity to move further upstream. Many recruiting juveniles, including catadromous eels, will use floods as a cue to enter the estuary and overcome obstacles to move upstream. Some sub/adults will leave the estuary to join the adult populations in the sea. Catadromous eels begin their return migration to the sea on floods. Connectivity between estuaries often occurs during floods. Major river flooding associated with high sediment loads can cause gill clogging and hypoxia for fish in the estuary. Large aggregations of kob and other fish with preferences for high turbidity often occur immediately adjacent to estuary mouths during floods. Estuarine connectivity driven by flood events.			to marginal areas or are flushed during floods. On rare occasions, sudden changes in salinity and osmotic shock may result in mortalities.	to marginal areas. High flow velocities may disrupt nesting and flush some introduced fish.
Salinities	*G aestuaria* tolerant of 0-53 psu. *C. spatulatus* 0-38 psu but could be tolerant of higher salinities.	All tend to be tolerant of low rather than high salinities but vulnerable to osmotic shock from abrupt changes in salinity. Preferred estuary salinity is highly variable ranging from 0-10 for *M. falciformis* to 15-30 for *L. lithognathus* to 0-35 for the opportunistic *L. richardsonii*. To reiterate, fish in TOEs are distributed according to salinity tolerance whereas those in permanently open ones are distributed according to salinity preference.			Tend to stay as close to 30-35 psu as possible. Stressed under 20 psu.	Highly variable most prefer much < 10 psu but *O. mossambicus* tolerant to hypersalinity of >180 psu.
Turbidity	*G. aestuaria* tends to stick to filter feeding under high turbidity. To date, no discernible response to turbidity *Clinus spatulatus* a visual predator but seems to be abundant in high and low turbidity. Predation by birds probably lower under high turbidity..	Highly variable. *A. breviceps* prefers less turbid water for selective feeding. *S. temminckii* similar.. *Caffrogobius* spp. often in high turbidity wind-mixed shallows. *Psammogobius* on lower turbidity sandy substrata.	Highly variable, *A. japonicus* prefers turbid water for refuge and foraging, sound and movement rather than sight used for detecting prey. Juvenile and sub-adult *L. lithognathus* prefer low turbidity for preying on zooplankton and benthic invertebrates.		Wide range of turbidity, usually clearer but turbulent surf-zone waters	Indigenous *Galaxias* likes clear blackwater, *O. mossambicus* from low to highly turbid, *C. carpio* likes very turbid water. *M. salmoides*, a piscivore, prefers clear waters for hunting.
Dissolved oxygen	All become stressed when oxygen drops below 4 $mg.l^{-1}$. Most estuary-associated fish have surface breathing as an adaptation to hypoxia. In fact, during periods of high algal and pondweed biomass, night-time plant respiration is likely to cause oxygen levels to plummet below 4 $mg.l^{-1}$ after daytime super-saturation. Eutrophication and persistent night-time low oxygen levels may exhaust fish to an extent that 'prolonged" mass mortalities occur as they recently did in the Klein. Skin respiration also an adaptation in some species e.g. mudskippers and probably the same in *Caffrogobius*, *Psammogobius* and *C. spatulatus* whereas sole gill morphology allows survival in hypoxic conditions.				Little tolerance to low oxygen levels/hypoxia and unable to practice surface breathing.	Indigenous *Galaxias* can cope with hypoxia by surface breathing and can even survive out of water within a moist sand/mud "cocoon". Probably able to aestivate & breathe through its skin. Cape kurper *Sandelia capensis* (in Klein?) has rudimentary air-breathing organs. Introduced *C. carpio* moderately tolerant of low oxygen whilst

<table>
<tr><th>Fish</th><th>Ia. Estuarine residents (breed only in estuaries)</th><th>Ib. Estuarine residents (breed in estuaries and the sea)</th><th>IIa. Estuary dependent marine species</th><th>IIb and c. Estuary associated species</th><th>III. Marine migrants</th><th>IV. Euryhaline freshwater species</th></tr>
<tr><td></td><td colspan="4"></td><td></td><td>O. mossambicus is more than able to cope and will often take advantage of hypoxic events by colonising areas previously excluded from.</td></tr>
<tr><td>Subtidal, intertidal and supratidal habitat</td><td colspan="4">With the exception of the gobies and Clinus spatulatus which can find refuge in invertebrate burrows & weed during low tide , all the fish are confined to the subtidal but forage in the intertidal during high tide. This is especially important for the Mugillidae which feed on bird & other faecal material and detritus resuspended on the high tide.</td><td>Mostly confined to the subtidal but may forage in the intertidal during high tide</td><td>With the exception of O. mossambicus, all will likley migrate upsteram into the freshwater reaches when the estuary is tidal.</td></tr>
<tr><td>Other abiotic components</td><td colspan="5">Low temperatures increase tolerance to hypoxia and low salinities and lower risk of mass mortality. Greater volumes maintain lower temperatures and thermoclines develop in the water column. Sex ratios can be skewed in fish where sex determination is temperature related. Increases in temperature tend to skew towards males, decreases towards females. Consequently, climate change and local scale anthropogenic influences on temperature could have a profound impact on fish populations. Growth rates and gonadal development tend to decrease either side of the optimal temperatures for individual species. Fish move according to their preferred temperature, constraints more in temporarily open/closed than permanently open estuaries.Many of the fish in southwestern Cape estuaries are tolerant of low pH inflow of blackwater systems e.g. Myxus capensis. Shallow marginal areas tend to be warmer than deeper channel areas and are thus favourable for metabolic processes. Juveniles and small adults also use shallow water as a predation refuge.</td><td>Indigenous fish adapted to low pH whereas introduced ones originate from high pH waters. Consequently, agricultural runoff raises pH to the advantage of the introduced species..</td></tr>
<tr><td rowspan="2">Sediment characteristics (including sedimentation)</td><td colspan="6">Individual species preferences are highly variable and often related to preferred food sources. Burying ability and crypsis of some fish (e.g. sole Heteromycteris capensis) are governed by sediment characteristics. Some fish are directly and indirectly impacted e.g. Psammogobius knysnaensis are psammophyllic but have commensal/mutual relationships with burrowing invertebrates which are distributed according to their burrowing ability and sediment characteristics.</td></tr>
<tr><td>C. spatulatus seems to prefer sandy areas but also found over mud.</td><td>Psammogobius associated with sand and Callianassa burrows, Caffrogobius spp. prefer mud/finer sediments.</td><td colspan="2">Highly variable across species. L. lithognathus juveniles prefer sandy substrata whereas the Mugillidae prefer sediments with a high proportion of fines (usually detrital). This said, benthic diatoms can be prolific on sand and a valuable food source. Callianassa bioturbation has been shown to greatly reduce benthic diatom production forcing Mugillidae to forage elsewhere</td><td>Highly variable across species but most persist over the sandy lower reaches of most estuaries.</td><td>Variable. O. mossambicus prefers sandy substrata for nesting.</td></tr>
<tr><td>Phytoplankton biomass</td><td colspan="6">High phytoplankton production contributes to turbidity in estuaries and probably favours those species with higher turbidity preferences. Phytoplankton is also a food source for filter-feeding fish e.g. G.aestuaria and invertebrates. Fish also benefit indirectly from proliferation of invertebrates that feed on phytoplankton. Omnivorous filter-feeding fish will out-compete selective feeders during periods of high phytoplankton biomass.

Harmful algal blooms in estuaries, usually a result of eutrophication, have a number of direct (toxicity) and indirect (e.g. hypoxia) impacts on fish. Blue-green Microcystis blooms, common in SA estuaries, can cause skin and/or organ lesions in fish resulting in poor health, reduced reproductive success and mortalities. Golden algae Prymnesium parvum, an invasive species recorded in Zandvlei, causes fatal gill haemorrhaging and induces abortion and premature spawning in fish.</td></tr>
<tr><td>Benthic micro-algae biomass</td><td colspan="2">G. aestuaria and A. breviceps may both selectively feed/graze on benthic diatoms.</td><td colspan="3">Mugillidae feed extensively on benthic micro-algae, stomach adapted to this with a gastric mill that uses sand to grind diatoms & other prey. South African fish biomass in estuaries is dominated by mullet (>60%) and therefore overall fish biomass is largely reflective of benthic algal biomass.</td><td></td></tr>
</table>

Fish	Ia. Estuarine residents (breed only in estuaries)	Ib. Estuarine residents (breed in estuaries and the sea)	IIa. Estuary dependent marine species	IIb and c. Estuary associated species	III. Marine migrants	IV. Euryhaline freshwater species
Zooplankton biomass	Depending on prey size and biomass*,* *G. aestuaria* and *A. breviceps* may both filter or selectively feed on zooplankton		Juveniles of all these species preferentially prey on zooplankton. Some e.g. *S. temminckii* will prey on zooplankton for their entire lives. Juvenile survival is probably dependent on a high zooplankton biomass where after many fish switch to benthic invertebrates or fish. One caveat is that predatory marine zooplankters (e.g. chaetognaths) may have a devastating impact on recruiting fish larvae. Jellyfish may do the same.			Feed mostly on insect larvae in freshwater reaches.
Aquatic macrophyte cover	*Clinus spatulatus* associated with high macrophyte cover especially *Zostera*.	C*affrogobius* and *S. temminckii* numbers fluctuate according to macrophyte cover.	Most of these fish will find refuge in macrophytes during the daytime but move into open water during the night as oxygen levels drop from plant respiration. Mullet will also graze macrophytes but probably after the epiphytes..			Find refuge but herbivorous *O. mossambicus* and to a lesser extent the omnivorous *C. carpio* graze macrophytes
Benthic invertebrate biomass	*G. aestuaria* and *A. breviceps* may both selectively feed/graze on small benthic invertebrates.		Most prey on benthic invertebrates, prey size/type depending on fish size. By example, *L. lithognathus* will switch from zooplankton to *Callianassa* & other benthic invertebrates once a year or so old.			All will prey on benthic invertebrates.
Fish biomass	*G. aestuaria* and *A. breviceps* are fodder-fish and comprise a high proportion of the fish biomass in the estuary. High predator biomass will suppress them. Burrow-associated fish (e.g. gobies) diversity and numbers will vary according to that of benthic invertebrates (e.g. sand prawn).		Piscivorous fish e.g. *P. saltatrix* & I rely on a high biomass of *G. aestuaria, A. breviceps* and Mugillidae in the estuary. Overall biomass in estuary greatly reduced by gillnetting. Fish biomass dominated by estuary associated marine species that utilise different food chains, e.g. groovy mullet *Liza dumerili* is a detritivore, white steenbras a zoobenthivore and leervis *Lichia amia*.Piscivores benefit from the high biomass of estuarine resident and small marine migrants in the estuary.			Introduced fish biomass a few orders of magnitude higher than endemic species.

3.10.4 Health of the fish component

Health scores for fish in the Klein estuary are presented in Table 3.44.

Table 3.44. Similarity scores of fish in the Present condition relative to the Reference condition.

Variable	Change from natural	Score	Confidence
1. Species richness	Overall, 51 species recorded in the estuary. Similar to reference and *Clinus spatulatus* has persisted in the system and has been subject to less population fluctuations than the Bot over the past 15 years. However, some estuarine-dependent species of very low numbers and functionally absent from the estuary whereas 6 alien species now in the upper reaches (Zone D). Marine species absent from the estuary.	80	H
2. Abundance	Numerically dominant *A. breviceps* and *G.aestuaria* have not changed much since reference but there has been a severe drop in recruitment and survival of estuarine-dependent marine species in the system more specifically those exploited. Further, in more than 250 seine hauls over 15 years, only 4 individual category III marine vagrants were caught. Freshwater invasives have established and increased in abundance in the upper reaches.	60	H
3. Community composition	Piscivorous fish specifically in much lower numbers e.g. *L. amia* or absent e.g. *A. japonicus* from the estuary. Small estuary-resident fodder fish probably unchanged but gillnet poaching has reduced numbers of marine opportunistic Mugillidae and therefore detritivores in the estuary. Introduced *Oreochromis mossambicus* herbivorous but also a fierce nest defender and being much larger usurps indigenous *Sandelia capensis* from the upper reaches.	70	H
Fish score		**60**	**H**
% due to non-flow related impacts		50	
Adjusted score		80	

3.11 Birds

3.11.1 Bird groups

For the purposes of this study, the birds found on the estuary have been grouped into nine groups (Table 3.45). Gulls and terns (mainly gulls) dominate the avifauna at present, with waders and waterfowl being the next two most common groups. Numbers of piscivorous birds actually feeding in the estuary (i.e. excluding gulls and terns) are low.

Table 3.45. Major bird groups found in the Klein estuary, and their defining features.

Bird groups	Defining features, typical/dominant species
Cormorants	These swimming piscivores catch their prey by following it under water and therefore prefer deeper water habitat. These include Reed Cormorant, Cape Cormorant, White-breasted Cormorant and African Darter.
Wading birds	This group comprises the egrets, herons, ibises and spoonbill. Loosely termed piscivores, their diet varies in plasticity, with fish usually dominating, but often also includes other vertebrates, such as frogs, and invertebrates. The ibises were included in this group, though their diet mainly comprises invertebrates and is fairly plastic. They tend to be tolerant of a wide range of salinities. Wading piscivores prefer shallow water up to a certain species dependant wading depth.
Piscivorous waterfowl	This group comprises the Grebes
Herbivorous waterfowl	This group is dominated by species that tend to occur in lower salinity or freshwater habitats and are associated with the presence of aquatic plants such as Potamageton and Phragmites. The group includes some of the ducks (e.g. Southern Pochard), and all the rallids (e.g. Redknobbed Coot).
Omnivorous waterfowl	This group comprises ducks which eat a mixture of plant material and invertebrate food such as small crustaceans - Yellow-billed Duck, Cape Teal, Red-billed Teal and Cape Shoveller. Although varying in tolerance, these species are fairly tolerant of more saline conditions.
Waders	This group includes all the waders in the order Charadriiformes (e.g. Greenshank, Curlew Sandpiper). They are the smallest species on the estuary, and feed on benthic macroinvertebrates in exposed and shallow intertidal areas. Invertebrate-feeding waders forage mainly on exposed sandbanks, mudflats and in the inter-tidal zone.
Gulls & terns	This group comprises the rest of the Charadriiformes, and includes all the gull and tern species using the estuary. These species are primarily piscivorous, but also take invertebrates. Most are euryhaline, but certain tern species on the estuary tend to be associated with low salinity environments. Gulls and terns can be very abundant and use the estuary primarily for roosting
Kingfishers	Kingfishers breed and perch on the river banks and prefer areas of open water with overhanging vegetation. They are largely piscivorous but also take other small prey.
Birds of prey	This group are not confined to a diet of fish, but also take other vertebrates and invertebrates. Species in this group include African Fish Eagle and African Marsh Harrier

3.11.2 Baseline description

3.11.2.1 Species richness and abundance

Species and counts from Underhill & Cooper 1984 and the 2001-2012 CWAC data mean and maximum counts are summarised in Table 3.46. A total of 71 waterbird species have been recorded on Klein Estuary. Across all CWAC counts 2001-2012, there were a total of 60 species recorded in summer and 53 in winter. The highest numbers of species recorded in any single count was 44 counted in January 1981 (Underhill & Cooper 1984) and 40 in February 2003 as well as March 2004 (CWAC data). The overall abundance of birds seems to have decreased from the 1981 survey (9974 birds) until the most recent comparable summer survey (February 2002). During 1981, a total of 9974 waterbirds were recorded at the estuary, compared with an average of 2007 birds in the CWAC counts. Evidence suggests that the 1981 count was not an anomaly. While 1200 waders were recorded in that count, a prior count (of waders only; Summers *et al*. 1976) recorded almost five times as many waders - total of 5406, of which 5057 were migratory species. Summers *et al.* (1977) considered the Klein estuary to be the third most important wetland in the Western Cape after Langebaan and the Berg estuary.

Table 3.46. Numbers of species recorded on the estuary by Underhill & Cooper (1984) and in 2001-2012 CWAC counts.

		CWAC Data 2001-2012			
		Summer		Winter	
Common Name	**Jan 81**	**Ave**	**Max**	**Ave**	**Max**
Grebe, Great Crested	36	3	16	2	13
Grebe, Black-necked	0	0	0	0	2
Grebe, Little	0	2	7	6	18
Pelican, Great White	0	0	2	0	0
Cormorant, White-breasted	39	32	78	30	92
Cormorant, Cape	0	3	18	2	6
Cormorant, Reed	2	26	75	31	82
Darter, African	1	1	6	2	8
Heron, Grey	31	13	31	6	12
Heron, Goliath	0	0	1	0	1
Heron, Purple	1	0	1	0	2
Egret, Little	31	9	62	6	27
Egret, Yellow-billed	0	0	1	0	0
Ibis, African Sacred	0	3	13	2	21
Spoonbill, African	48	13	61	4	16
Flamingo, Greater	11	60	430	5	35
Flamingo, Lesser	1	0	0	0	0
Goose, Spur-winged	0	1	12	2	19
Goose, Egyptian	0	17	69	13	45
Shoveler, Cape	513	86	222	34	180
Duck, African Black	0	0	2	0	0
Duck, Yellow-billed	565	151	409	63	187

		CWAC Data 2001-2012			
		Summer		Winter	
Common Name	**Jan 81**	**Ave**	**Max**	**Ave**	**Max**
Teal, Red-billed	0	4	28	1	8
Teal, Cape	0	11	32	11	47
Duck, Maccoa	0	0	0	0	2
Duck, White-backed	0	0	0	0	2
Fish-eagle, African	1	1	2	1	3
Marsh-harrier, African	1	0	0	0	1
Osprey, Osprey	0	0	3	0	1
Rail, African	0	0	0	0	1
Crake, Black	0	0	1	0	1
Moorhen, Common	0	0	3	1	6
Coot, Red-knobbed	2728	911	4670	1761	7600
Oystercatcher, African Black	4	28	56	28	78
Turnstone, Ruddy	0	0	2	0	0
Plover, Common Ringed	107	2	29	0	0
Plover, White-fronted	0	26	158	20	76
Plover, Kittlitz's	114	8	35	5	30
Plover, Three-banded	34	3	11	5	15
Plover, Grey	2	7	30	0	0
Lapwing, Blacksmith	24	10	26	7	15
Sandpiper, Curlew	167	29	179	0	0
Stint, Little	90	7	44	0	0
Knot, Red	0	1	17	0	0
Sanderling, Sanderling	1	0	0	0	0
Ruff, Ruff	352	3	12	0	0
Sandpiper, Common	30	2	15	0	1
Sandpiper, Marsh	14	0	2	0	0
Greenshank, Common	58	13	36	0	1
Sandpiper, Wood	5	1	4	0	0
Godwit, Bar-tailed	0	0	2	0	0
Curlew, Eurasian	1	0	2	0	1
Whimbrel, Common	19	17	58	1	8
Avocet, Pied	121	0	0	0	0
Stilt, Black-winged	74	16	55	12	50
Thick-knee, Water	1	0	2	0	2
Gull, Kelp	31	66	258	38	119
Gull, Grey-headed	0	0	4	0	2
Gull, Hartlaub's	104	109	286	57	242
Tern, Caspian	5	6	26	2	7
Tern, Common	3452	297	1500	6	40
Tern, Sandwich	632	28	106	2	12
Tern, Swift	469	27	144	19	74

Common Name	Jan 81	CWAC Data 2001-2012			
		Summer		Winter	
		Ave	Max	Ave	Max
Tern, Unidentified	0	1	20	1	20
Kingfisher, Pied	20	3	6	2	6
Kingfisher, Giant	1	0	1	0	2
Kingfisher, Malachite	0	0	0	0	1
Wagtail, Cape	31	6	16	8	25
Total	**9974**	**2067**	**5745**	**2196**	**8459**
Average number of species	**30**	**32**	**39**	**26**	**32**

There was much variation in bird numbers both in summer and winter over the period 2001 to 2012 (Figure 3.36). There is no clear indication of a decline in bird numbers overall or for either of the seasons separately during this time.

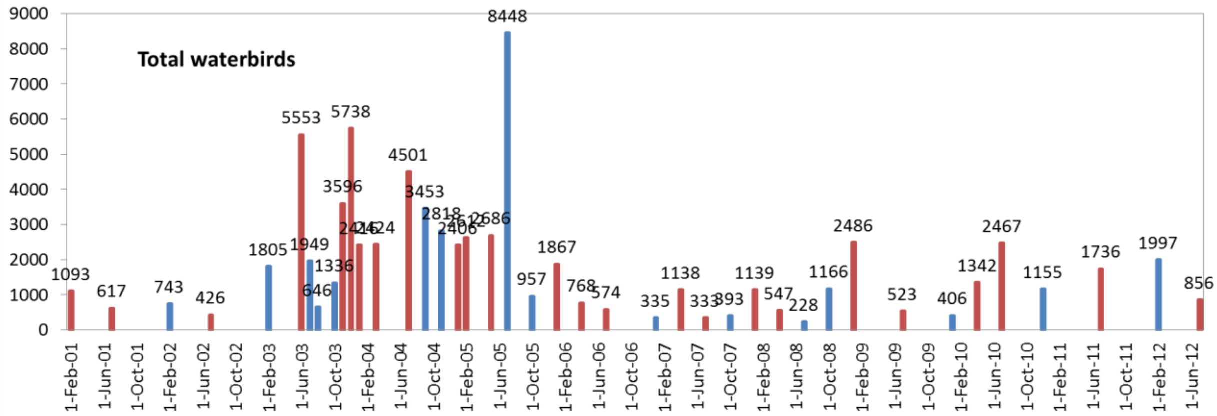


Figure 3.36. Total number of birds counted in summer (red) and winter (blue) at Klein Estuary (2001-2012 CWAC data).

3.11.2.2 Community composition

The composition recorded during the recent summer CWAC surveys was quite different from that recorded in January 1981 (Underhill & Cooper 1984; Figure 3.37). In the earlier survey the community had a higher proportion of gulls and terns (89%), mainly due to very high numbers of the migratory Common Tern. The herbivorous waterfowl component of the community was the second most abundant group in 1984 but numbers have been relatively low in recent counts.

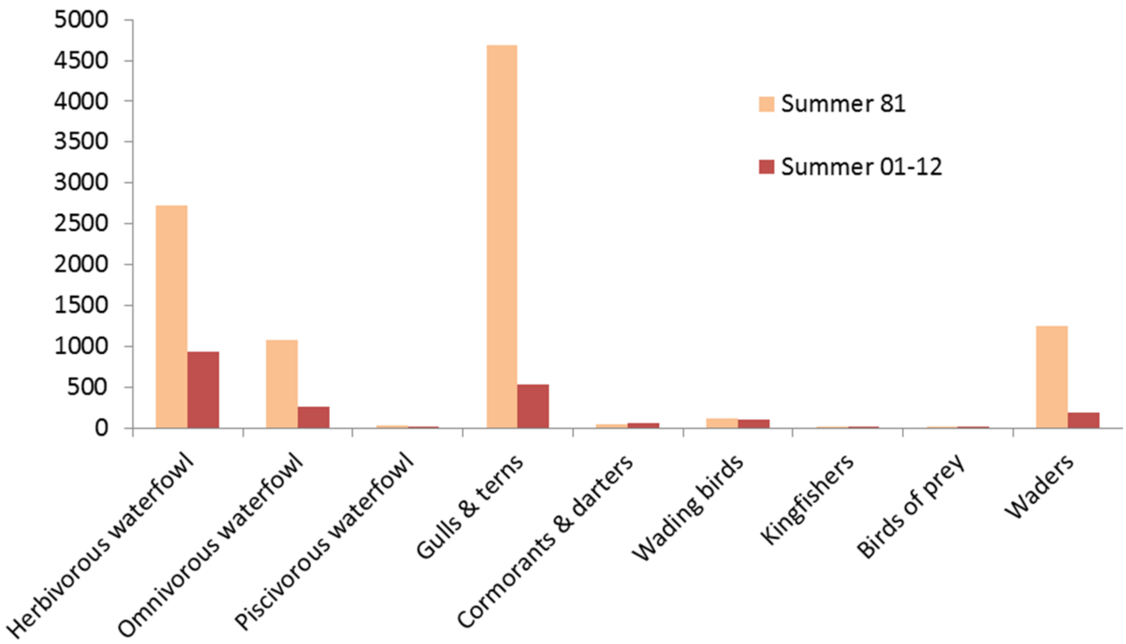


Figure 3.37. Average summer counts of different groups of birds in most recent summer count as well as Underhill & Cooper 1984.

During 2001-2012, the avifauna of the Klein Estuary was dominated by piscivorous gulls and terns (40%) and herbivorous waterfowl (22%) in summer (Figure 3.38), with the former group being dominated by the migratory Common Tern. In winter, the bird community was heavily dominated by herbivorous waterfowl (76%). These were mainly Red-knobbed Coot, which was by far the most common bird on the estuary. The numbers of waders are higher in summer due to an influx of migrants. The numbers of omnivorous waterfowl are also higher in summer, when fresh and brakwater areas are scarcer than in winter in this winter rainfall area.

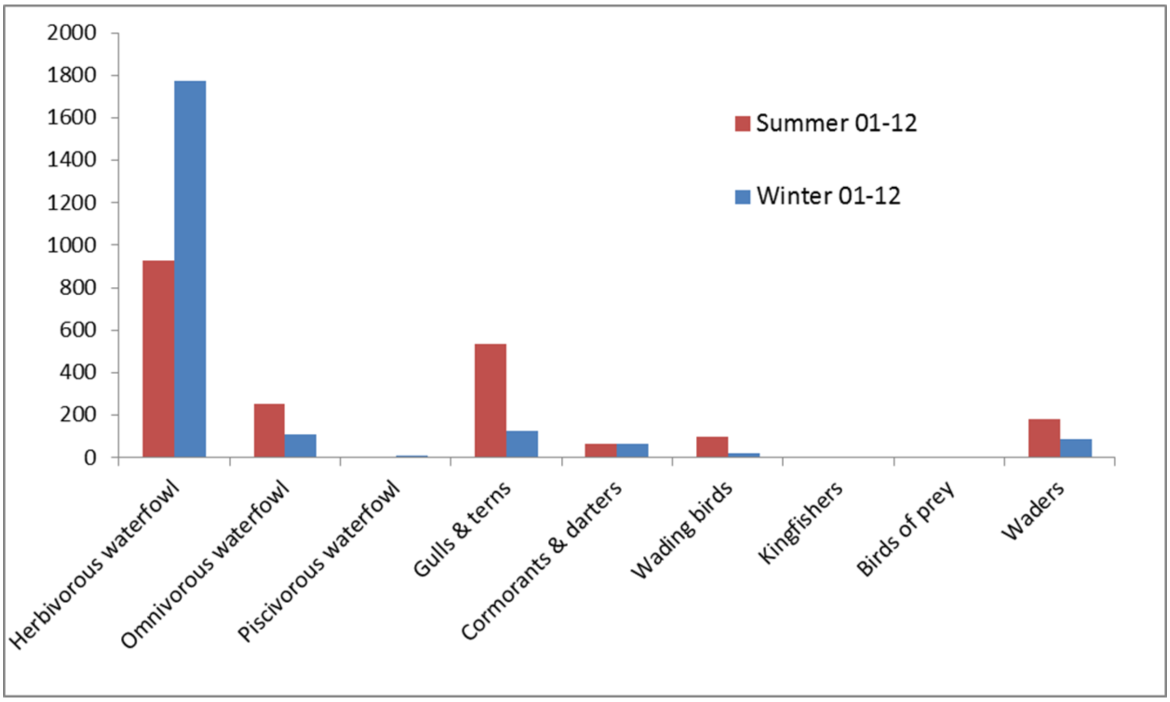


Figure 3.38. Average counts of different groups of birds in summer and winter (2001-2012 CWAC data).

In 1981, both waders and herbivorous waterfowl were concentrated at the head of the estuary, whereas other waterfowl and the gulls and terns were closer to the mouth (Figure 3.39).

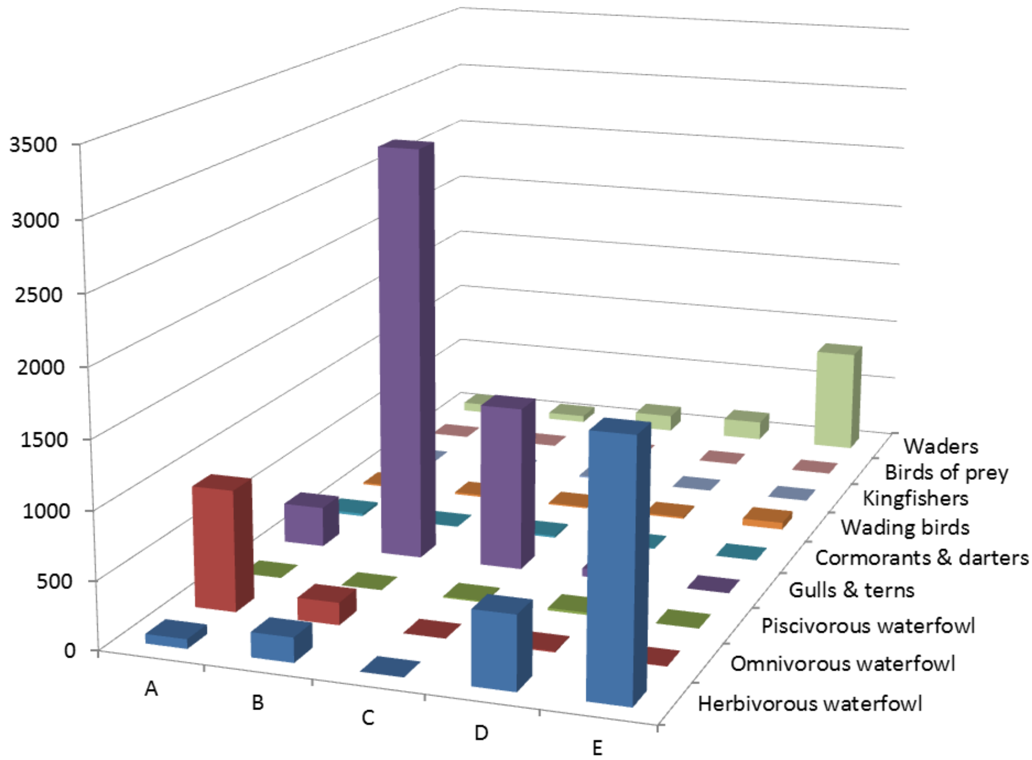


Figure 3.39. Distribution along the estuary in January 1981. The counting areas are from the mouth area (A) to the head of the estuary (E) , but the boundaries of these areas are unknown.

3.11.2.3 Dietary guilds

During 2001-2012, the avifauna was dominated by piscivores (mainly gulls and cormorants) in summer and herbivores (mainly coots) in winter (Figure 3.40). The percentage of benthivores (mainly waders) and omnivores is greater in summer than in winter.

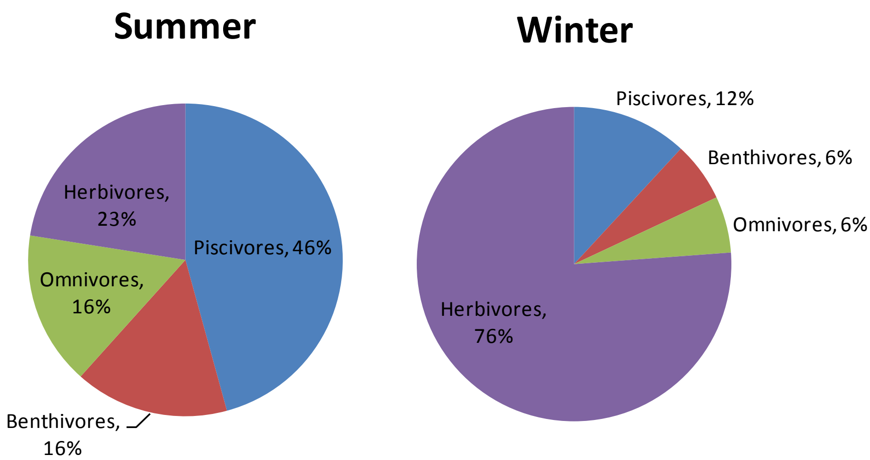


Figure 3.40. Percentage composition of different dietary guilds in summer and winter at Klein Estuary during summer 1981 (left) and on average during summer and winter of 2001-2012 (CWAC data.)

Benthivorous waders are opportunistic foragers whose diets reflect the macroinvertebrate fauna and are typically dominated by prawns (*Upogebia*), crabs (e.g. *Hymenosoma*), polychaetes (e.g. *Ceratonereis*) and amphipods.

The piscivorous birds include the gulls, which also eat invertebrates, the cormorants, terns, kingfishers, ospreys and fish eagles which concentrate on fish (although fish eagles do take other vertebrate prey), and the herons and egrets, which include a variety of vertebrates (e.g. frogs) in their diet. Piscivore numbers are higher in summer, consisting mainly of migratory birds such as certain terns.

The omnivorous species comprise most of the waterfowl, which consume small invertebrates as well as plant material. They are dominated by the Yellow-billed Duck. The herbivore group consists of waterfowl that tend to feed predominantly on submerged macrophytes which make up a large area of the Klein Estuary. This group is dominated by the Red-knobbed Coot.

3.11.3 Factors driving waterbird community structure and abundance

Some of the main flow-related influencing factors to be considered in estimating the bird community under reference conditions and the alternative scenarios are listed in Table 3.47.

Table 3.47. Effect of abiotic characteristics and processes, as well as other biotic components on bird groupings

Factor	Cormorants & wading piscivores	Kingfishers & fish-eagle	Waterfowl	Waders, gulls and terns
Mouth condition	Indirectly, through influence on water level and fish		Indirectly, through influence on macrophytes	Mouth closures has negative effect on preferred sandbanks in lower estuary
Salinities			Certain species of waterfowl prefer lower salinities	
Turbidity	Negatively affects visibility for foraging	Negatively affects visibility for foraging		Negatively affects visibility for foraging
Intertidal area				
Sediment characteristics (including sedimentation)				
Primary productivity	Indirectly though influence on food supply			
Submerged macrophytes abundance			Has positive influence on herbivorous waterfowl numbers	
Abundance of reeds and sedges			Has positive influence on some herbivorous waterfowl species	
Abundance of zooplankton			Assumed positive for some omnivorous species	
Benthic invertebrate abundance				
Fish biomass	Piscivores will increase with increasing numbers of small to medium-sized fish			

3.11.4 The Reference condition

Since the reference conditions prevailed, there has been a reduction in low flows, leading to lower water levels and a slight increase in salinity and turbidity. Artificial breaching at lower than natural levels has resulted in reduction in scouring, sedimentation in the mouth area, and the system being open for 22% of the time instead of 30%. There has also been siltation of the upper reaches due to catchment erosion. The Open & Brackish states have both been reduced by more time in closed marine state. There is increased water retention time, increased nutrient inputs (farming & WWTW) and hence increased productivity. Some habitat loss has occurred in marginal areas (development), and there is increased human disturbance (Hermanus, Stanford) and fishing. In addition to these changes, there have been regional and global changes in the populations of some species. The reference condition was conservatively taken to be similar to those found in 1981, and the expected changes are summarised below (Table 3.48).

Table 3.48. Summary of how the bird groups in the Present condition have changed relative to the Reference condition.

Parameters	Present
Cormorants	Increased salinity and WB cormorant population, possibly not such a large change on average
Wading birds	Reduced fish (60%), decr habitat, disturbance
Herbivorous waterfowl	Increased salinity, lower water levels, reduced fw subm macrophytes
Other waterfowl	Increased salinity, lower water levels, reduced emergent veg
Waders	Reduced open period, loss of upper marsh open habitat?
Gulls & terns	Human disturbance in mouth area, reduced open period
Birds of prey	Reduction of fish biomass, human disturbance
Kingfishers	Reduced fish biomass, reduced marginal habitat, human disturbance

3.11.5 Health of the avifaunal component

Health scores for fish in the Klein estuary under Present day conditions are presented in Table 3.49.

Table 3.49. Similarity scores of birds in the Present condition relative to the Reference condition.

Variable	Change from natural	Score	Confidence
1. Species richness	Reduction in average instantaneous species richness (based on data)	90	M
2. Abundance	Numbers of nearly all groups has declined, with overall decrease in numbers. Massive decrease in gulls & terns, waterfowl and wader numbers.	21	M
3. Community composition	Reduced numbers of some of the more numerous groups – waterfowl, terns, so big change in community composition	34	M
Bird score	**Min: 1-3**	**21**	
% impact due to non-flow related impacts - Global losses in numbers of migratory waders; increases in the western cape of certain species of wading birds and waterfowl; increased estuary productivity due to pollution.		55	
Adjusted score		64	

Ryan (2013) recorded massive declines in coastal birds in the Western Cape from the 1980s to the 2010, particularly for waders and terns. Some of this decline is due to changes on breeding grounds elsewhere, but much of the change is also like to be due to changes in the coastal habitats such as the Klein estuary, and levels of human disturbance within these habitats. It is important to note that without the external effects, the score would be more moderate.

3.12 PRESENT ECOLOGICAL STATUS

3.12.1 Overall EHI score

The Estuarine Health Index (EHI) scores allocated to the various abiotic and biotic health parameters for the Klein estuary and the overall Present Ecological Status (PES) for the system under the present state are calculated from the overall EHI score (Table 3.50).

Table 1 summarises the above findings. The EHI score for the Klein Estuary in its present state was estimated to be 62 (i.e. 62% similar to natural condition, which translates into a Present Ecological Status (PES) of C. This arises from significant changes in the hydrology (MAR), mouth status, water quality, microalgae and bird fauna.

Table 3.50. PES scores and descriptions

EHI score	Present Ecological Status	General description
91 – 100	A	Unmodified, natural
76 – 90	B	Largely natural with few modifications
61 – 75	C	Moderately modified
41 – 60	D	Largely modified
21 – 40	E	Highly degraded
0 – 20	F	Extremely degraded

Table 3.51. Estuarine Health Score (EHI) for the Kleine estuary, the estimated Estuarine Health Score with non-flow related impacts removed, and confidence levels (scores are derived to produce overall confidence).

Variable	Health score/100	Health score net of non-flow related impacts	Confidence score	Confidence
Hydrology	77	77	70	Med
Hydrodynamics and mouth condition	72	93	50	Low
Water quality	81	98	70	Med
Physical habitat alteration	65	97	50	Low
Habitat health score	**74**	**91**	**60**	**Low**
Microalgae	65	83	50	Low
Macrophytes	70	76	70	Med
Invertebrates	70	76	50	Low
Fish	60	80	50	Low
Birds	21	64	50	Low
Biotic health score	**57**	**76**	**54**	**Low**
ESTUARY HEALTH SCORE	**65**	**83**	**57**	**Low**
PRESENT ECOLOGICAL STATUS	**C**	**B**		
OVERALL CONFIDENCE	**Low**			

3.12.2 Relative contribution of flow and non-flow related impacts on health

Estimates of the contribution of non-flow related impacts on the level of degradation of each component led to an adjusted health score of 83, which would raise the PES to a B category. This suggests that non-flow impacts have played a major role in the degradation of the estuary to a C, but that flow-related impacts are still an important cause of its degradation. Thus the highest priority is to address the quantity and quality of influent water. Of the non-flow-related impacts, elevated nutrient inputs from the catchment and artificial breaching of the mouth of the estuary were found to be the most important factors that influenced the health of the system.

3.12.3 Overall confidence

Confidence levels were very low for two of the abiotic components (Hydrodynamics and mouth condition and Physical habitat alteration) and most of the biotic components (all except macrophytes). This most mostly due to the lack of historic information (i.e. the state of the estuary under Natural conditions). The overall confidence of the study was LOW (Table 3.51).

The implications of this are that

(c) one has to be extremely cautious and apply the precautionary principle in setting the Preliminary Reserve; and
(d) efforts should be made to collect baseline and monitoring data that will help to fill some key gaps in understanding.

Key gaps in our understanding pertain to both the abiotic and biotic aspects of the estuary. The primary gap is the lack of good data on rainfall and abstractions in the catchment. Hydrological understanding would also be improved with better flow data and so that estimates of daily flows can be derived.

4 THE RECOMMENDED ECOLOGICAL CATEGORY

4.1 Conservation Importance of the Klein Estuary

The Estuary Importance Score (EIS) for the estuary takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account (Table 4.2). Biodiversity importance, in turn is based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices. These importance scores ideally refer to the system in its natural condition. The scores have been determined for all South African estuaries, apart from functional importance, which is scored by the specialists in the workshop. In this case, functional importance was deemed to be relatively high (100%), because of its importance as a movement corridor for river fish breeding in the sea (eels), its importance as a nursery area for marine fish and as a roosting area for coastal birds. The EIS for the Klein Estuary, based on its present state, was therefore estimated to be 93, i.e., the estuary is rated as "Highly important" (Table 4.3).

Table 4.1. Estimation of the functional importance score of the Klein estuary

Functional importance score	
a. Estuary: Input of detritus and nutrients generated in estuary	30
b. Nursery function for marine-living fish and crustaceans	80
c. Movement corridor for river invertebrates and fish breeding in sea	100
d. Roosting area for marine or coastal birds	80
e. Catchment detritus, nutrients and sediments to sea	80
Functional importance score - Max (a to e)	**100**

Table 4.2. Importance scores (EIS) for the Klein estuary

Criterion	**Weight**	**Score**
Estuary Size	15	15
Zonal Rarity Type	10	10
Habitat Diversity	25	25
Biodiversity Importance	25	25
Functional Importance	25	25
Weighted Estuary Importance Score		**93**

Table 4.3. Estuarine importance scores (EIS) and significance

Importance score	**Description**
81 – 100	Highly important
61 – 80	Important
0 – 60	Of low to average importance

4.2 Recommended Ecological Category

The Recommended Ecological Category (REC) represents the level of protection assigned to an estuary. The first step is to determine the 'minimum' EC, based on its PES. The relationship between EHI Score, PES and minimum REC is set out in Table 4.4.

Table 4.4. Relationship between the EHI, PES and minimum ERC

EHI SCORE	PES	DESCRIPTION	MINIMUM EC
91 – 100	A	Unmodified, natural	A
76 – 90	B	Largely natural with few modifications	B
61 – 75	C	Moderately modified	C
41 – 60	D	Largely modified	D
21 – 40	E	Highly degraded	-
0 – 20	F	Extremely degraded	-

The PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of **importance** and level of **protection or desired** protection of a particular estuary (Table 4.2). The Klein estuary does not have any statutory protection status at present but is included in the subset of estuaries identified as requiring protection in order to conserve South Africa estuarine biodiversity estate (Turpie *et al.* 2004, Turpie & Clark 2007, Turpie *et al.* 2012). Thus, according to the rules laid down in DWA (2012), the REC for the Klein estuary is thus an “A” Class or “Best attainable State” (BAS).

Table 4.2. Estuary protection status and importance, and the basis for assigning a recommended ecological reserve category

Protection status and importance	Recommended Ecological Category	Policy basis
Protected area	A or BAS*	Protected and desired protected areas should be restored to and maintained in the best possible state of health
Desired Protected Area (based on complementarity)		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B category
Important	PES + 1, min C	Important estuaries should be in an A, B or C category
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D category

* BAS = Best Attainable State

The PES for the Klein is a C. The estuary is rated as “Highly important”, and it is a designated as a desired protected area in the Biodiversity Plan for the National Biodiversity Assessment (Turpie *et al.* 2012). Thus the **Recommended Ecological Category** for the estuary is its “Best Attainable State” i.e. a B.

5 OPERATIONAL AND ECOLOGICAL RESERVE SCENARIOS

5.1 Description of the Scenarios

Although there are no firm plans for increased utilisation of water in the Klein River catchment, a number of hypothetical scenarios were constructed to examine likely impacts of further decreases (transfers out of the catchment) as well as some increases (restoration) in flow on the health of the Klein estuary. Restoration in flows was assumed to be achieved through removal of Invasive Alien plants (IAPs) and or reduction in water use for irrigation. The following scenarios were considered:

- Scenario 1: + 20% of Present (i.e. 16% reduction from Natural)
- Scenario 2: + 10% of Present (i.e. 26% reduction from Natural)
- Scenario 3: - 10% of Present (i.e. 33% reduction from Natural)
- Scenario 4: - 20% of Present (i.e. 40% reduction from Natural)
- Scenario 5: - 30% of Present (i.e. 50% reduction from Natural)
- Scenario 6: - 40% of Present (i.e. 55% reduction from Natural)

Summary data on MAR for the Reference, Present Day and operational scenarios is presented in Table 5.1.

Table 5.1. Summary of the scenarios evaluated in this study

Scenario name	Description	MAR (x 10^6 m^3)	Percentage remaining
Natural	Reference condition	53.41	
Present	Present day	40.88	76.5
Scenario 1	+ 20% of Present (remove all IAPs, reduce irrigation by 46%)	52.08	97.5
Scenario 2	+ 10% of Present (remove all IAPs)	49.43	92.6
Scenario 3	- 12% of Present (i.e. 33% reduction from Natural)	40.00	74.9
Scenario 4	- 21% of Present (i.e. 40% reduction from Natural)	36.17	67.7
Scenario 5	- 28% of Present (i.e. 49% reduction from Natural)	31.45	58.9
Scenario 6	- 41% of Present (i.e. 55% reduction from Natural)	28.03	52.5

Data on flow into the estuary at Stanford and flows out of the estuary into the sea as well as use by various sectors (irrigation, domestic, transfers out of the catchment, invasive alien plants), evaporation from the estuary, and contribution by agricultural return flows are presented in Table 5.2 and Table 5.3.

Table 5.2. Summary of modelled flow results (flows into the estuary at Stanford).

Scenario	Description	Into Estuary	Irrigation	Domestic	Transfer Out	IAP	Evaporation	Return flows	% change
Natural		53.41							
Present Day		40.88	6.37	0.44	0.00	4.12	1.87	0.50	23.45
Scenario 1	Increased flow	44.89	6.70	0.44	0.00	0.00	1.87	0.50	15.94
Scenario 2	Increased flow	47.54	3.60	0.44	0.00	0.00	1.87	0.28	10.98
Scenario 3	Reduced flow	36.05	6.70	0.44	3.50	4.12	2.76	0.50	32.50
Scenario 4	Reduced flow	32.22	6.70	0.44	7.00	4.12	3.00	0.50	39.67
Scenario 5	Reduced flow	27.50	6.70	0.44	10.90	4.12	3.87	0.50	48.50
Scenario 6	Reduced flow	24.08	3.60	0.44	13.30	4.12	4.38	0.50	54.92

Table 5.3. Summary of modelled flow results (flows into the sea).

Scenario	Description	Out of estuary	Irrigation	Domestic	Transfer Out	IAP	Evaporation	Return flows	% change
Natural		57.85							
Present Day		38.66	6.37	0.44	0.00	4.12	9.33	0.77	33.17
Scenario 1	Increased flow	41.50	6.70	0.44	0.00	0.00	9.34	0.77	28.26
Scenario 2	Increased flow	44.01	3.60	0.44	0.00	0.00	9.34	0.77	23.92
Scenario 3	Reduced flow	34.09	6.70	0.44	3.50	4.12	10.17	0.77	41.06
Scenario 4	Reduced flow	30.41	6.70	0.44	7.00	4.12	10.45	0.77	47.42
Scenario 5	Reduced flow	25.69	6.70	0.44	10.90	4.12	11.22	0.77	55.59
Scenario 6	Reduced flow	22.31	3.60	0.44	13.30	4.12	11.67	0.55	61.44

The water resources modelling of the Klein River catchment shows that even under natural conditions, flow in December through to the end of March can be very low, close to zero at times. Under present day conditions, the flow is reduced by 23% on average, with very low flows observed from December through to the end of March.

Further development within the catchment without the implementation of operating rules to implement the ecological Reserve will further reduce the flow as well as result in longer periods of low flows.

5.2 Abiotic Components

This section summarises the estimated changes in each of the abiotic components under the different scenarios, and provides expected health scores for each.

5.2.1 Hydrology

The modelled changes in hydrology are summarised in Table 5.4 and scored in Table 5.5. Note that the final hydrology score (Table 5.5) is based solely on the score for % similarity in MAR as the Klein estuary is classified as an estuarine lake (Whifield 1992) and responds to river flow in all its variability rather than to flooding alone. The contribution by floods for movement of sediment in this system is less important than in other estuary types owing to the fact that scouring in the mouth region is dependent on the water level and volume of water in the estuary prior to breaching rather than flood magnitude or frequency *per se*. This approach is in line with the method for determination of the estuarine reserve (DWA 2012).

Table 5.4. Summary of changes under the different scenarios.

<table>
<tr><th>Parameter</th><th>Scenarios 1-6</th></tr>
<tr><td>Similarity in MAR</td><td>The Klein Estuary responds to river flow in all its variability. Breaching is dependent on the total inflow, while the duration of the open period responds to the breaching level, mouth position and occurrence of higher flow event post breaching.</td></tr>
<tr><td>Changes in the occurrences and magnitudes of floods</td><td>Scenario 1 shows a significant increase in flood volumes, while Scenario 2, 3 and 4 are similar to the present. For Scenario 5 to 6, however, which incorporate dam developments near the head of the estuary, there is a severe reduction in floods to the system.
<table>
<tr><th></th><th>Present</th><th>Sc 1</th><th>Sc 2</th><th>Sc 3</th><th>Sc 4</th><th>Sc 5</th><th>Sc 6</th></tr>
<tr><td>Change in floods</td><td>87</td><td>96</td><td>94</td><td>84</td><td>81</td><td>72</td><td>66</td></tr>
</table>
</td></tr>
</table>

Table 5.5. Similarity scores for hydrology relative to the Reference condition.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Confidence
% similarity in MAR	77	98	93	75	67	59	53	M
Hydrology score	77	98	93	75	67	59	53	

5.2.2 Hydrodynamics and mouth condition

Mouth conditions were sensitive to the changes in river flow to the estuary. Under Scenario 1 and 2, mouth condition revert to a more natural regime, while under Scenario 3 to 6 the mouth of the estuary will be less open than under the current conditions. The water column structure (stratification) will remain relatively similar to the reference conditions, but will become more homogenous in Zone C and D under the future Scenarios 4 to 6. Water retention time also remain relatively similar to the present, with retention time increasing (increase in closed mouth conditions) significantly under the future Scenarios 3 to 6. Water levels increase slightly under the future scenario 1 and 2, and decrease under Scenarios 3 to 6, with a nearly 20cm average decrease under Scenario 6.

Modelled changes in hydrodynamic functioning, monthly changes in average water level and occurrence of different abiotic states in the Klein estuary are summarised in Table 5.6-Table 5.11 and Figure 5.1.

Table 5.6. Klein Estuary simulated average monthly water level (m to MSL) under Scenario 1. Colour coding indicates likley occurrence of different abiotic states as follows: State 1: Open marine, 2: Open gradient, 3: Closed marine, 4: Closed brakish, 5: Closed hypersaline.

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.642	0.564	0.448	0.301	0.193	0.074	0.031	-0.001	0.000	0.000	0.000	0.000
1921	0.726	0.641	0.529	0.515	0.393	0.353	0.298	0.288	1.327	1.430	1.962	2.100
1922	2.137	0.000	0.000	0.000	0.000	0.480	0.851	1.829	2.422	0.000	0.000	0.000
1923	0.000	1.870	1.796	1.649	1.516	1.418	1.363	1.316	0.000	0.000	0.000	0.000
1924	0.713	0.935	0.853	0.713	0.568	0.446	0.389	0.342	0.000	0.000	0.000	0.000
1925	0.847	0.842	0.706	0.535	0.400	0.288	0.225	0.238	0.288	2.387	0.000	0.000
1926	0.000	0.000	0.459	0.292	0.173	0.055	-0.003	0.106	0.159	0.189	0.834	0.938
1927	0.923	0.867	0.748	0.602	0.459	0.356	0.277	0.238	0.396	0.389	0.478	0.668
1928	0.647	0.615	0.480	0.307	0.170	0.077	0.034	0.035	0.053	0.983	1.230	1.336
1929	1.332	1.266	1.147	0.997	0.891	0.835	0.805	0.851	0.869	0.901	1.337	1.902
1930	2.021	2.005	1.858	1.694	1.555	1.444	1.922	1.985	2.003	0.000	0.000	0.000
1931	0.000	0.657	0.535	0.382	0.292	0.172	0.095	0.171	0.330	0.483	0.592	0.000
1932	0.000	0.000	0.000	0.433	0.291	0.180	0.118	0.142	1.034	1.470	0.000	0.000
1933	0.000	0.000	0.435	0.263	0.122	0.009	-0.074	-0.090	-0.102	0.116	0.939	1.804
1934	2.120	2.111	1.961	1.798	1.652	1.540	1.572	1.957	2.242	2.482	0.000	0.000
1935	0.000	0.000	0.472	0.381	0.250	0.131	0.070	0.163	0.218	0.347	0.470	0.621
1936	0.663	0.675	0.601	0.447	0.303	0.211	0.163	0.136	0.800	0.000	0.000	0.000
1937	0.000	0.546	0.418	0.276	0.131	0.125	0.158	0.330	0.437	0.617	0.915	0.000
1938	0.000	0.000	0.000	0.434	0.372	0.308	0.298	0.319	0.325	0.622	1.398	1.627
1939	1.679	1.606	1.471	1.310	0.000	0.000	0.000	0.000	1.190	1.427	1.562	1.735
1940	1.771	1.915	1.778	1.621	1.475	1.350	2.359	0.000	0.000	0.000	0.000	0.000
1941	0.987	0.985	0.872	0.724	0.576	0.463	0.409	0.939	1.775	1.979	2.203	2.404
1942	2.468	2.376	2.316	0.000	0.000	0.000	0.000	0.717	0.804	1.033	1.410	1.732
1943	1.868	1.922	1.794	1.635	1.482	1.359	1.302	2.002	0.000	0.000	0.000	0.000
1944	1.024	0.981	0.847	0.673	0.521	0.399	0.381	0.000	0.000	0.000	0.000	1.338
1945	2.488	0.000	0.000	0.000	0.000	0.685	0.639	0.646	0.732	0.820	0.914	1.387
1946	1.499	1.401	1.247	1.076	0.932	0.878	0.831	0.848	0.872	2.282	2.561	0.000
1947	0.000	0.000	0.000	0.441	0.295	0.323	0.322	0.323	0.425	0.667	0.751	0.885
1948	0.000	0.000	0.000	0.000	0.458	0.328	0.449	0.556	0.614	0.719	1.066	1.248
1949	1.306	1.512	1.393	1.221	1.070	0.944	0.987	0.977	0.985	1.484	1.565	1.800
1950	1.909	2.264	2.189	2.179	2.046	1.943	2.165	2.259	0.000	0.000	0.000	0.000
1951	1.267	1.243	1.095	0.932	0.795	0.677	0.632	0.676	0.747	1.025	2.098	0.000
1952	0.000	0.000	0.000	0.446	0.305	0.179	0.392	0.479	0.642	1.106	1.318	1.435
1953	1.461	1.550	1.405	1.240	1.109	1.009	1.018	0.000	0.000	0.000	0.000	1.318
1954	1.442	1.396	1.259	1.094	0.000	0.000	0.000	0.000	0.791	1.916	0.000	0.000
1955	0.000	0.000	0.471	0.301	0.173	0.089	0.041	1.404	2.461	0.000	0.000	0.000
1956	0.000	0.547	0.551	0.402	0.293	0.203	0.174	2.443	0.000	0.000	0.000	0.000
1957	0.000	0.880	0.730	0.557	0.448	0.426	0.419	2.433	0.000	0.000	0.000	0.000
1958	0.721	0.664	0.512	0.365	0.226	0.137	2.166	0.000	0.000	0.000	0.000	1.050
1959	1.490	1.492	1.348	1.190	1.043	0.942	0.895	0.962	1.436	1.644	1.776	1.863
1960	1.860	1.748	1.660	1.654	1.528	1.420	1.365	1.413	1.568	1.727	2.223	0.000
1961	0.000	0.000	0.000	0.488	0.354	0.316	0.359	0.359	1.752	2.038	0.000	0.000
1962	0.000	0.000	0.465	0.315	0.174	0.063	0.024	0.003	0.039	0.693	1.843	2.030
1963	2.083	2.012	1.911	1.752	1.632	1.559	1.515	1.511	0.000	0.000	0.000	0.000
1964	0.766	1.546	1.569	1.411	1.298	1.250	1.231	1.350	1.410	1.530	1.657	1.703
1965	1.726	1.633	1.498	1.332	1.188	1.077	1.090	1.108	1.121	1.424	0.000	0.000
1966	0.000	0.000	0.447	0.281	0.137	0.037	1.612	1.821	0.000	0.000	0.000	0.000
1967	0.728	0.692	0.544	0.399	0.265	0.147	0.094	0.172	0.746	0.950	1.425	1.591
1968	1.684	1.622	1.469	1.329	1.191	1.075	1.130	1.119	1.196	1.229	1.276	1.283
1969	1.303	1.197	1.031	0.864	0.750	0.617	0.539	0.536	0.726	1.092	2.106	2.390
1970	2.533	2.464	2.327	2.157	2.016	1.900	1.860	1.867	1.979	2.346	0.000	0.000
1971	0.000	0.000	0.489	0.329	0.196	0.091	0.239	0.368	0.526	0.674	1.538	1.868
1972	1.967	1.879	1.730	1.562	1.412	1.287	1.217	1.247	1.256	1.351	1.397	1.462
1973	1.431	1.341	1.195	1.035	0.893	0.772	0.692	1.005	1.063	1.091	0.000	0.000
1974	0.000	0.000	0.452	0.300	0.149	0.026	-0.018	0.262	0.304	0.748	1.626	1.833
1975	2.019	1.968	1.806	1.630	1.490	1.389	1.519	1.600	0.000	0.000	0.000	0.000
1976	0.863	1.084	0.986	0.822	0.841	0.745	0.718	1.161	1.626	0.000	0.000	0.000
1977	0.000	0.560	0.589	0.451	0.326	0.234	0.198	0.190	0.190	0.797	1.528	1.772
1978	1.890	1.814	1.700	1.559	2.364	2.386	2.310	2.586	0.000	0.000	0.000	0.000
1979	1.046	1.049	0.918	0.764	0.628	0.495	0.447	0.485	0.867	0.924	1.004	1.037
1980	1.039	1.360	1.300	1.564	1.521	1.492	1.907	1.990	2.053	0.000	0.000	0.000
1981	0.000	0.563	0.427	0.280	0.133	0.035	1.345	1.514	1.719	1.806	1.967	2.076
1982	2.062	1.950	1.798	1.636	1.639	1.569	1.519	0.000	0.000	0.000	0.000	1.341
1983	1.526	1.502	1.356	1.188	1.052	0.948	0.914	2.084	2.268	2.444	2.565	0.000
1984	0.000	0.000	0.000	0.581	0.484	0.391	0.477	0.478	0.543	0.000	0.000	0.000
1985	0.000	0.578	0.431	0.259	0.128	0.081	0.039	0.007	0.069	0.179	0.000	0.000
1986	0.000	0.000	0.468	0.310	0.181	0.058	0.157	0.267	0.489	0.638	1.543	2.116
1987	2.272	2.180	2.049	1.876	1.747	1.626	1.769	1.825	1.988	2.069	0.000	0.000
1988	0.000	0.000	0.458	0.299	0.170	0.858	0.000	0.000	0.000	0.000	0.000	2.342
1989	0.000	0.628	0.490	0.336	0.240	0.121	0.754	1.278	0.000	0.000	0.000	0.000
1990	0.657	0.588	0.444	0.294	0.145	0.031	-0.036	0.022	0.208	0.000	0.000	0.000
1991	0.000	0.719	0.587	0.429	0.306	0.197	0.197	0.343	0.811	1.045	1.522	2.212
1992	0.000	0.000	0.000	0.000	0.513	0.395	0.000	0.000	0.000	0.000	2.478	0.000
1993	0.000	0.515	0.404	0.247	0.112	-0.003	0.004	0.069	0.000	0.000	0.000	0.000
1994	0.699	0.611	0.684	0.559	0.416	0.551	0.585	1.133	1.338	1.802	0.000	0.000
1995	0.000	0.000	0.811	0.671	0.554	0.442	0.370	0.350	0.493	1.124	1.372	1.693
1996	0.000	0.000	0.000	0.000	0.467	0.340	0.319	1.570	2.022	2.207	2.495	0.000
1997	0.000	0.000	0.000	0.449	0.305	0.208	0.368	0.000	0.000	0.000	0.000	0.829
1998	0.844	1.303	0.000	0.000	0.000	0.000	0.636	0.655	0.673	0.684	0.973	2.130
1999	2.265	2.177	2.046	1.917	1.770	1.769	1.725	1.738	1.760	2.156	2.322	2.594
2000	0.000	0.000	0.000	0.000	0.459	0.334	0.291	0.314	0.314	1.838	0.000	0.000
2001	0.000	0.000	0.460	0.730	0.675	0.551	0.528	0.693	1.086	1.913	0.000	0.000
2002	0.000	0.000	0.450	0.305	0.168	0.000	0.000	0.000	0.000	0.686	0.000	0.000
2003	0.000	0.000	0.474	0.333	0.199	0.091	0.058	0.029	0.088	0.336	0.450	0.513
2004	2.526	0.000	0.000	0.000	0.000	0.476	0.000	0.000	0.000	0.000	0.991	1.243

Table 5.7. Klein Estuary simulated average monthly water level (m to MSL) under Scenario 2. Colour coding indicates likley occurrence of different abiotic states as follows: State 1: Open marine, 2: Open gradient, 3: Closed marine, 4: Closed brakish, 5: Closed hypersaline.

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.623	0.534	0.413	0.266	0.158	0.039	-0.014	-0.047	0.000	0.000	0.000	0.000
1921	0.697	0.599	0.479	0.455	0.326	0.276	0.217	0.204	1.188	1.261	1.765	1.874
1922	1.884	0.000	0.000	0.000	0.000	0.480	0.819	1.759	2.321	0.000	0.000	0.000
1923	0.000	1.841	1.744	1.593	1.460	1.362	1.307	1.261	2.485	2.583	0.000	0.000
1924	0.000	0.000	0.509	0.368	0.224	0.102	0.045	-0.002	0.000	0.000	0.000	0.000
1925	0.818	0.787	0.641	0.470	0.335	0.224	0.160	0.168	0.210	2.241	0.000	0.000
1926	0.000	0.000	0.448	0.281	0.162	0.044	-0.014	0.072	0.103	0.117	0.707	0.780
1927	0.739	0.669	0.543	0.397	0.254	0.151	0.072	0.033	0.168	0.152	0.217	0.351
1928	0.308	0.255	0.114	-0.059	-0.196	-0.290	-0.333	-0.334	-0.326	0.543	0.746	0.823
1929	0.793	0.716	0.591	0.440	0.334	0.271	0.235	0.275	0.287	0.307	0.679	1.194
1930	1.279	1.240	1.086	0.923	0.783	0.672	1.096	1.148	1.151	1.891	0.000	0.000
1931	0.000	0.000	0.469	0.315	0.218	0.098	0.021	0.089	0.220	0.331	0.401	0.000
1932	0.000	0.000	0.000	0.433	0.291	0.180	0.118	0.132	0.969	1.365	0.000	0.000
1933	0.000	0.000	0.433	0.261	0.120	0.007	-0.076	-0.092	-0.106	0.088	0.845	1.674
1934	1.961	1.924	1.767	1.603	1.458	1.345	1.360	1.705	1.950	2.162	2.287	2.445
1935	2.475	2.429	2.293	2.193	2.062	1.943	1.882	1.956	2.000	2.098	2.173	2.287
1936	2.302	2.285	2.198	2.041	1.897	1.806	1.758	1.730	2.338	0.000	0.000	0.000
1937	0.000	0.528	0.392	0.249	0.104	0.093	0.110	0.253	0.338	0.473	0.742	0.000
1938	0.000	0.000	0.000	0.434	0.356	0.286	0.271	0.279	0.275	0.507	1.251	1.447
1939	1.470	1.382	1.240	1.079	0.000	0.000	0.000	0.000	1.156	1.364	1.470	1.615
1940	1.621	1.737	1.592	1.435	1.289	1.164	2.126	0.000	0.000	0.000	0.000	0.000
1941	0.958	0.932	0.809	0.658	0.510	0.398	0.344	0.826	1.629	1.804	1.999	2.171
1942	2.206	2.102	2.024	0.000	0.000	0.000	0.000	0.684	0.741	0.938	1.286	1.579
1943	1.686	1.712	1.575	1.415	1.262	1.139	1.082	1.744	0.000	0.000	0.000	0.000
1944	0.995	0.936	0.795	0.622	0.470	0.347	0.323	0.000	0.000	0.000	0.000	1.310
1945	2.430	2.595	2.465	2.307	2.164	2.226	2.173	2.174	2.242	2.302	2.359	0.000
1946	0.000	0.000	0.000	0.429	0.285	0.220	0.172	0.182	0.195	1.532	1.782	1.887
1947	1.948	1.875	1.716	1.557	1.411	1.430	1.419	1.413	1.496	1.712	1.758	1.848
1948	0.000	0.000	0.000	0.000	0.458	0.328	0.425	0.515	0.555	0.632	0.939	1.093
1949	1.122	1.301	1.171	0.999	0.848	0.722	0.745	0.730	0.733	1.175	1.225	1.432
1950	1.513	1.827	1.736	1.701	1.562	1.459	1.644	1.720	0.000	0.000	0.000	0.000
1951	1.238	1.195	1.040	0.877	0.740	0.622	0.577	0.613	0.670	0.919	1.937	0.000
1952	0.000	0.000	0.000	0.442	0.301	0.174	0.358	0.420	0.550	0.986	1.169	1.251
1953	1.248	1.309	1.156	0.991	0.860	0.760	0.763	0.000	0.000	0.000	0.000	1.290
1954	1.384	1.323	1.179	1.014	0.000	0.000	0.000	0.000	0.753	1.848	0.000	0.000
1955	0.000	0.000	0.463	0.293	0.165	0.080	0.033	1.339	2.367	0.000	0.000	0.000
1956	0.000	0.526	0.514	0.359	0.248	0.157	0.123	2.332	0.000	0.000	0.000	0.000
1957	0.000	0.851	0.694	0.521	0.411	0.369	0.353	2.315	0.000	0.000	0.000	0.000
1958	0.692	0.619	0.461	0.314	0.175	0.085	2.063	0.000	0.000	0.000	0.000	1.021
1959	1.433	1.406	1.255	1.097	0.950	0.848	0.801	0.847	1.277	1.447	1.552	1.610
1960	1.580	1.459	1.365	1.345	1.213	1.104	1.050	1.091	1.227	1.365	1.813	2.250
1961	2.362	2.264	2.107	1.990	1.856	1.812	1.842	1.832	0.000	0.000	0.000	0.000
1962	1.892	2.067	1.920	1.769	1.628	1.517	1.478	1.445	1.468	2.070	0.000	0.000
1963	0.000	0.000	0.491	0.332	0.213	0.133	0.088	0.079	1.424	1.830	0.000	0.000
1964	0.000	0.000	0.609	0.449	0.336	0.282	0.256	0.345	0.386	0.477	0.561	0.579
1965	0.574	0.469	0.328	0.162	0.018	-0.093	-0.086	-0.074	-0.067	0.197	1.385	1.717
1966	1.776	1.673	1.516	1.351	1.206	1.107	0.000	0.000	0.000	0.000	1.400	1.676
1967	1.775	1.719	1.564	1.418	1.285	1.167	1.113	1.169	1.686	1.851	2.291	2.427
1968	2.492	2.414	2.255	2.114	1.977	1.860	1.897	1.880	1.938	1.959	1.987	1.977
1969	1.975	1.859	1.694	1.526	1.408	1.274	1.197	1.193	1.359	1.662	0.000	0.000
1970	0.000	0.000	0.458	0.287	0.147	0.030	-0.010	-0.009	0.084	0.408	1.639	1.855
1971	1.931	1.857	1.738	1.577	1.444	1.339	1.463	1.549	1.675	1.791	0.000	0.000
1972	0.000	0.000	0.447	0.279	0.129	0.004	-0.066	-0.042	-0.038	0.036	0.064	0.106
1973	0.059	-0.039	-0.184	-0.345	-0.487	-0.607	-0.688	-0.398	-0.350	-0.335	0.000	0.000
1974	0.000	0.000	0.444	0.292	0.140	0.018	-0.027	0.230	0.257	0.648	1.476	1.654
1975	1.812	1.742	1.575	1.398	1.259	1.158	1.274	1.335	0.000	0.000	0.000	0.000
1976	0.834	1.027	0.913	0.745	0.740	0.638	0.605	1.003	1.434	0.000	0.000	0.000
1977	0.000	0.543	0.551	0.406	0.282	0.190	0.151	0.142	0.138	0.705	1.386	1.602
1978	1.687	1.595	1.475	1.334	2.099	2.113	2.037	2.279	2.465	0.000	0.000	0.000
1979	0.000	0.581	0.443	0.290	0.154	0.020	-0.027	0.004	0.338	0.361	0.412	0.417
1980	0.396	0.681	0.611	0.847	0.793	0.741	1.120	1.181	1.216	2.183	0.000	0.000
1981	0.000	0.000	0.456	0.309	0.163	0.064	1.317	1.474	1.642	1.699	1.831	1.911
1982	1.879	1.760	1.608	1.446	1.438	1.358	1.308	0.000	0.000	0.000	0.000	1.312
1983	1.468	1.428	1.276	1.107	0.972	0.868	0.833	1.953	2.104	2.251	2.343	2.565
1984	0.000	0.000	0.000	0.000	0.497	0.396	0.454	0.444	0.487	0.000	0.000	0.000
1985	0.000	0.552	0.397	0.225	0.094	0.039	-0.009	-0.042	0.000	0.088	0.000	0.000
1986	0.000	0.000	0.461	0.302	0.173	0.050	0.126	0.212	0.385	0.507	1.377	1.921
1987	2.048	1.943	1.807	1.634	1.505	1.384	1.511	1.559	1.696	1.756	2.321	2.511
1988	2.594	2.505	2.357	2.199	2.069	0.000	0.000	0.000	0.000	0.000	0.000	2.314
1989	0.000	0.600	0.451	0.298	0.196	0.077	0.668	1.160	0.000	0.000	0.000	0.000
1990	0.628	0.545	0.395	0.245	0.096	-0.019	-0.085	-0.034	0.126	0.000	0.000	0.000
1991	0.000	0.691	0.551	0.394	0.271	0.162	0.154	0.276	0.691	0.898	1.346	2.000
1992	0.000	0.000	0.000	0.000	0.507	0.389	0.000	0.000	0.000	0.000	2.449	0.000
1993	0.000	0.503	0.386	0.229	0.094	-0.021	-0.022	0.021	0.000	0.000	0.000	0.000
1994	0.670	0.568	0.616	0.483	0.340	0.461	0.487	0.995	1.173	1.602	0.000	0.000
1995	0.000	0.000	0.783	0.636	0.519	0.406	0.334	0.315	0.434	1.013	1.229	1.519
1996	0.000	0.000	0.000	0.000	0.467	0.340	0.313	1.509	1.931	2.088	2.347	2.459
1997	2.502	0.000	0.000	0.000	0.000	0.504	0.640	0.000	0.000	0.000	0.000	0.800
1998	0.788	1.218	0.000	0.000	0.000	0.000	0.629	0.640	0.650	0.649	0.908	2.012
1999	2.118	2.017	1.881	1.751	1.604	1.595	1.544	1.553	1.567	1.906	2.041	2.285
2000	2.307	2.193	2.047	1.888	1.748	1.622	1.579	1.595	1.588	0.000	0.000	0.000
2001	0.000	0.548	0.402	0.645	0.582	0.459	0.431	0.562	0.920	1.712	0.000	0.000
2002	0.000	0.000	0.443	0.298	0.160	0.000	0.000	0.000	0.000	0.657	0.000	0.000
2003	0.000	0.000	0.467	0.325	0.191	0.083	0.041	0.011	0.061	0.283	0.357	0.380
2004	2.348	2.398	2.261	2.198	2.061	1.937	0.000	0.000	0.000	0.000	0.962	1.185

Table 5.8. Klein Estuary simulated average monthly water level (m to MSL) under Scenario 3. Colour coding indicates likley occurrence of different abiotic states as follows: State 1: Open marine, 2: Open gradient, 3: Closed marine, 4: Closed brakish, 5: Closed hypersaline.

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.587	0.486	0.365	0.219	0.112	-0.006	-0.059	-0.091	0.000	0.000	0.000	0.000
1921	0.641	0.514	0.394	0.326	0.192	0.129	0.071	0.060	0.743	0.779	1.219	1.284
1922	1.252	0.000	0.000	0.000	0.000	0.481	0.585	1.406	1.898	0.000	0.000	0.000
1923	0.000	1.719	1.570	1.420	1.289	1.193	1.139	1.094	1.975	2.037	0.000	0.000
1924	0.000	0.000	0.464	0.324	0.181	0.060	0.005	-0.040	0.000	0.000	0.000	0.000
1925	0.766	0.687	0.538	0.368	0.235	0.125	0.063	0.071	0.101	1.647	1.956	2.098
1926	0.000	0.000	0.000	0.000	0.483	0.366	0.309	0.344	0.338	0.330	0.626	0.657
1927	0.579	0.489	0.363	0.218	0.077	-0.025	-0.102	-0.139	-0.101	-0.123	-0.104	-0.089
1928	-0.169	-0.248	-0.391	-0.562	-0.698	-0.789	-0.831	-0.832	-0.830	-0.510	-0.356	-0.322
1929	-0.393	-0.483	-0.610	-0.759	-0.865	-0.932	-0.967	-0.938	-0.933	-0.923	-0.871	-0.463
1930	-0.438	-0.521	-0.677	-0.839	-0.977	-1.087	-0.947	-0.940	-0.946	-0.312	0.783	1.054
1931	1.862	1.827	1.689	1.537	1.441	1.322	1.247	1.290	1.338	1.368	1.372	0.000
1932	0.000	0.000	0.000	0.435	0.294	0.186	0.126	0.132	0.589	0.919	0.000	0.000
1933	0.000	0.000	0.435	0.265	0.125	0.014	-0.068	-0.082	-0.095	-0.050	0.353	1.066
1934	1.292	1.203	1.044	0.882	0.738	0.627	0.619	0.680	0.870	1.033	1.114	1.228
1935	1.212	1.119	0.982	0.871	0.740	0.622	0.562	0.602	0.625	0.666	0.678	0.666
1936	0.610	0.524	0.417	0.262	0.119	0.029	-0.017	-0.042	0.190	1.995	2.257	0.000
1937	0.000	0.000	0.000	0.458	0.314	0.279	0.273	0.310	0.339	0.381	0.538	2.413
1938	0.000	0.000	0.000	0.000	0.507	0.433	0.410	0.407	0.395	0.465	0.998	1.136
1939	1.112	0.999	0.858	0.699	2.057	2.284	2.490	2.488	0.000	0.000	0.000	0.000
1940	0.559	0.616	0.458	0.303	0.159	0.035	0.655	1.570	2.386	0.000	0.000	0.000
1941	0.000	0.528	0.396	0.248	0.101	-0.010	-0.063	0.099	0.806	0.930	1.082	1.209
1942	1.196	1.076	0.973	1.610	1.496	1.413	1.386	1.398	1.412	1.548	1.842	2.078
1943	2.131	2.106	1.958	1.801	1.649	1.527	1.472	1.808	0.000	0.000	0.000	0.000
1944	0.916	0.814	0.670	0.498	0.347	0.226	0.198	0.000	0.000	0.000	0.000	1.186
1945	2.171	2.258	2.118	1.960	1.818	1.777	1.721	1.723	1.766	1.785	1.795	2.025
1946	2.054	1.926	1.772	1.603	1.460	1.386	1.339	1.346	1.349	2.243	2.437	2.499
1947	2.512	2.409	2.251	2.093	1.949	1.924	1.901	1.895	1.947	1.999	1.983	1.985
1948	0.000	0.000	0.000	0.000	0.459	0.331	0.332	0.380	0.395	0.423	0.523	0.627
1949	0.609	0.725	0.579	0.410	0.260	0.136	0.130	0.116	0.121	0.234	0.239	0.393
1950	0.424	0.668	0.550	0.452	0.314	0.213	0.243	0.275	0.000	0.000	0.000	0.000
1951	1.114	1.026	0.867	0.706	0.570	0.454	0.411	0.432	0.465	0.518	1.264	2.489
1952	0.000	0.000	0.000	0.000	0.461	0.336	0.368	0.392	0.453	0.784	0.918	0.954
1953	0.904	0.912	0.755	0.591	0.462	0.364	0.357	2.495	0.000	0.000	0.000	0.000
1954	0.641	0.546	0.400	0.236	2.278	2.271	2.222	2.200	2.247	0.000	0.000	0.000
1955	0.000	0.542	0.398	0.229	0.103	0.019	-0.027	0.894	1.803	2.196	0.000	0.000
1956	0.000	0.000	0.535	0.376	0.267	0.176	0.143	1.960	0.000	0.000	0.000	0.000
1957	0.000	0.757	0.594	0.422	0.314	0.245	0.219	1.814	2.058	2.116	0.000	0.000
1958	0.000	0.000	0.443	0.298	0.160	0.072	1.600	2.460	2.561	0.000	0.000	0.000
1959	0.000	0.517	0.362	0.205	0.060	-0.040	-0.086	-0.068	0.033	0.161	0.222	0.237
1960	0.167	0.040	-0.061	-0.130	-0.266	-0.372	-0.425	-0.396	-0.320	-0.262	-0.063	0.303
1961	0.361	0.227	0.071	-0.045	-0.178	-0.236	-0.238	-0.256	0.725	0.928	0.000	0.000
1962	0.000	0.000	0.439	0.289	0.149	0.039	0.002	-0.034	-0.023	0.231	1.205	1.312
1963	1.291	1.183	1.068	0.911	0.793	0.712	0.668	0.661	1.584	1.920	0.000	0.000
1964	0.000	0.000	0.530	0.371	0.260	0.195	0.164	0.198	0.213	0.242	0.255	0.215
1965	0.154	0.035	-0.103	-0.268	-0.409	-0.519	-0.522	-0.514	-0.508	-0.382	0.380	0.643
1966	0.649	0.526	0.371	0.207	0.064	-0.033	1.074	1.198	1.880	2.155	0.000	0.000
1967	0.000	0.000	0.443	0.299	0.167	0.051	-0.001	0.017	0.212	0.335	0.704	0.790
1968	0.808	0.699	0.542	0.402	0.267	0.151	0.155	0.134	0.166	0.169	0.168	0.130
1969	0.093	-0.032	-0.196	-0.361	-0.478	-0.609	-0.685	-0.688	-0.624	-0.546	0.063	0.257
1970	0.315	0.199	0.058	-0.111	-0.250	-0.365	-0.404	-0.402	-0.350	-0.258	0.704	0.869
1971	0.896	0.786	0.661	0.502	0.371	0.269	0.260	0.291	0.325	0.360	1.074	1.320
1972	1.338	1.210	1.059	0.893	0.744	0.620	0.552	0.576	0.581	0.618	0.616	0.607
1973	0.533	0.430	0.286	0.127	-0.014	-0.133	-0.212	-0.136	-0.116	-0.116	0.000	0.000
1974	0.000	0.000	0.441	0.290	0.140	0.019	-0.024	0.028	0.034	0.266	0.986	1.114
1975	1.220	1.109	0.943	0.769	0.631	0.531	0.583	0.598	0.000	0.000	0.000	0.000
1976	0.779	0.910	0.767	0.599	0.534	0.429	0.394	0.590	0.959	0.000	0.000	0.000
1977	0.000	0.506	0.447	0.294	0.171	0.080	0.042	0.034	0.031	0.257	0.834	0.997
1978	1.030	0.908	0.786	0.646	1.161	1.104	1.029	1.176	1.320	1.543	1.814	1.928
1979	2.268	2.190	2.052	1.900	1.766	1.634	1.589	1.611	1.676	1.658	1.661	1.628
1980	1.579	1.743	1.623	1.757	1.655	1.576	1.852	1.867	1.878	0.000	0.000	0.000
1981	0.000	0.502	0.356	0.210	0.065	-0.032	0.849	0.942	1.072	1.091	1.185	1.224
1982	1.159	1.035	0.885	0.724	0.674	0.589	0.540	1.602	2.412	0.000	0.000	0.000
1983	0.000	0.518	0.362	0.195	0.061	-0.042	-0.075	0.663	0.761	0.870	0.921	1.096
1984	1.361	1.252	1.147	1.062	0.952	0.851	0.862	0.838	0.864	0.000	0.000	0.000
1985	0.000	0.506	0.349	0.178	0.049	-0.018	-0.065	-0.098	-0.077	-0.038	0.000	0.000
1986	0.000	0.000	0.452	0.295	0.167	0.045	0.051	0.088	0.120	0.140	0.894	1.356
1987	1.427	1.296	1.161	0.989	0.861	0.741	0.800	0.813	0.863	0.874	1.210	1.350
1988	1.384	1.263	1.116	0.959	0.830	1.200	0.000	0.000	0.000	0.000	0.000	2.118
1989	2.553	2.495	2.338	2.185	2.085	1.968	2.294	0.000	0.000	0.000	0.000	0.780
1990	0.757	0.647	0.494	0.346	0.198	0.086	0.021	0.057	0.120	2.201	2.398	2.557
1991	0.000	0.000	0.000	0.000	0.478	0.370	0.351	0.395	0.555	0.712	1.092	1.653
1992	2.319	2.344	2.202	2.043	1.949	1.832	0.000	0.000	0.000	0.000	2.252	2.563
1993	2.526	2.411	2.293	2.137	2.003	1.890	1.876	1.887	0.000	0.000	0.000	0.000
1994	0.623	0.497	0.465	0.321	0.180	0.198	0.184	0.566	0.701	1.071	2.283	2.539
1995	0.000	0.000	0.000	0.000	0.484	0.373	0.302	0.284	0.335	0.644	0.808	1.044
1996	2.275	2.507	2.383	2.226	2.093	1.968	1.939	0.000	0.000	0.000	0.000	0.662
1997	0.659	0.759	0.605	0.455	0.312	0.218	0.273	0.000	0.000	0.000	0.000	0.748
1998	0.690	1.027	0.000	0.000	0.000	0.000	0.603	0.607	0.612	0.603	0.714	1.565
1999	1.606	1.486	1.352	1.223	1.077	1.037	0.985	0.995	1.007	1.053	1.109	1.297
2000	1.268	1.139	0.995	0.838	0.699	0.575	0.534	0.544	0.537	1.519	2.197	2.507
2001	0.000	0.000	0.000	0.000	0.490	0.368	0.341	0.366	0.622	1.320	2.377	0.000
2002	0.000	0.000	0.000	0.456	0.320	0.000	0.000	0.000	0.000	0.625	0.000	0.000
2003	0.000	0.000	0.465	0.324	0.192	0.086	0.042	0.013	0.048	0.120	0.130	0.103
2004	1.731	1.713	1.571	1.473	1.337	1.214	0.000	0.000	0.000	0.000	0.908	1.079

Table 5.9. Klein Estuary simulated average monthly water level (m to MSL) under Scenario 4. Colour coding indicates likley occurrence of different abiotic states as follows: State 1: Open marine, 2: Open gradient, 3: Closed marine, 4: Closed brakish, 5: Closed hypersaline.

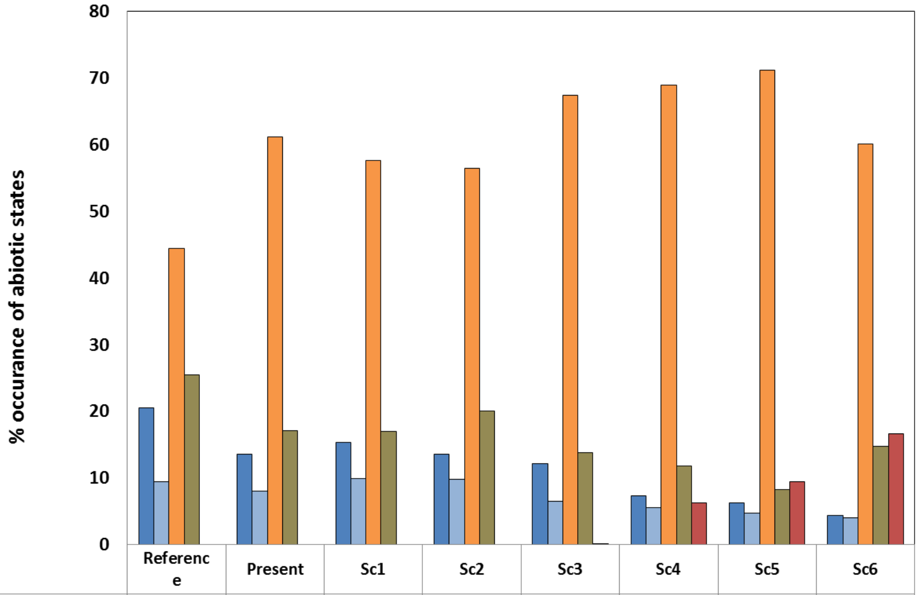
YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.587	0.486	0.365	0.219	0.112	-0.006	-0.059	-0.091	0.000	0.000	0.000	1.055
1921	1.066	0.939	0.819	0.751	0.617	0.554	0.496	0.485	0.943	0.951	1.366	1.404
1922	1.343	0.000	0.000	0.000	0.451	0.332	0.436	1.118	1.586	2.326	0.000	0.000
1923	0.000	1.691	1.536	1.386	1.254	1.158	1.105	1.059	1.742	1.778	0.000	0.000
1924	0.000	0.700	0.564	0.424	0.281	0.160	0.106	0.060	0.000	0.000	0.000	0.767
1925	0.906	0.802	0.654	0.484	0.351	0.241	0.179	0.187	0.217	1.518	1.802	1.918
1926	0.000	0.000	0.000	0.434	0.316	0.200	0.143	0.178	0.172	0.163	0.203	0.207
1927	0.129	0.039	-0.087	-0.232	-0.373	-0.475	-0.553	-0.589	-0.551	-0.573	-0.554	-0.539
1928	-0.619	-0.698	-0.841	-1.012	-1.148	-1.239	-1.281	-1.282	-1.280	-1.161	-1.145	-1.185
1929	-1.260	-1.351	-1.478	-1.627	-1.732	-1.800	-1.835	-1.806	-1.801	-1.791	-1.739	-1.696
1930	-1.745	-1.828	-1.984	-2.146	-2.284	-2.394	-2.330	-2.323	-2.329	-2.022	-0.951	-0.706
1931	0.075	0.009	-0.129	-0.281	-0.377	-0.496	-0.571	-0.528	-0.480	-0.450	-0.446	1.786
1932	2.009	1.889	1.749	1.583	1.443	1.334	1.274	1.281	1.511	1.816	0.000	0.000
1933	0.000	0.484	0.319	0.149	0.009	-0.102	-0.183	-0.198	-0.210	-0.166	-0.030	0.639
1934	0.837	0.719	0.559	0.398	0.253	0.143	0.135	0.196	0.283	0.300	0.354	0.442
1935	0.397	0.295	0.157	0.046	-0.084	-0.202	-0.262	-0.222	-0.199	-0.158	-0.146	-0.158
1936	-0.215	-0.300	-0.407	-0.562	-0.705	-0.795	-0.841	-0.867	-0.761	0.614	0.849	1.220
1937	1.290	1.180	1.040	0.899	0.755	0.720	0.714	0.750	0.779	0.821	0.863	2.559
1938	0.000	0.000	0.000	0.435	0.342	0.268	0.246	0.243	0.230	0.301	0.564	0.675
1939	0.621	0.508	0.368	0.208	1.450	1.647	1.828	1.826	2.265	2.400	2.433	2.510
1940	2.447	2.463	2.305	2.150	2.006	1.882	2.352	0.000	0.000	0.000	1.657	0.000
1941	0.000	0.000	0.468	0.319	0.172	0.062	0.009	0.108	0.661	0.759	0.885	0.986
1942	0.944	0.824	0.721	1.268	1.154	1.071	1.043	1.055	1.070	1.123	1.316	1.528
1943	1.551	1.497	1.350	1.192	1.041	0.919	0.864	1.021	0.000	0.000	0.000	0.000
1944	0.887	0.786	0.641	0.469	0.318	0.197	0.169	0.000	0.000	0.000	0.000	1.159
1945	2.119	2.176	2.035	1.878	1.736	1.695	1.639	1.641	1.683	1.703	1.712	1.788
1946	1.753	1.625	1.471	1.302	1.159	1.085	1.038	1.045	1.048	1.605	1.772	1.808
1947	1.792	1.689	1.531	1.374	1.230	1.204	1.181	1.175	1.227	1.279	1.263	1.265
1948	0.000	0.000	0.000	0.446	0.305	0.177	0.178	0.226	0.241	0.269	0.344	0.342
1949	0.287	0.241	0.095	-0.074	-0.224	-0.348	-0.353	-0.368	-0.363	-0.283	-0.297	-0.273
1950	-0.321	-0.162	-0.280	-0.379	-0.517	-0.618	-0.588	-0.558	2.039	0.000	0.000	0.000
1951	1.085	0.986	0.828	0.666	0.531	0.414	0.371	0.393	0.426	0.478	0.954	2.156
1952	2.437	0.000	0.000	0.000	0.461	0.336	0.368	0.392	0.453	0.566	0.673	0.682
1953	0.617	0.582	0.425	0.262	0.132	0.034	0.027	1.993	2.557	0.000	0.000	0.000
1954	0.612	0.517	0.371	0.207	2.136	2.098	2.049	2.027	2.074	0.000	0.000	0.000
1955	0.850	0.762	0.617	0.448	0.322	0.238	0.192	0.939	1.827	2.196	0.000	0.000
1956	0.000	0.473	0.406	0.246	0.137	0.047	0.013	1.640	0.000	0.000	0.000	1.495
1957	0.000	0.000	0.000	0.428	0.320	0.252	0.225	1.646	1.866	1.897	0.000	0.000
1958	0.000	0.488	0.331	0.186	0.048	-0.040	1.322	2.159	2.234	2.347	0.000	0.000
1959	0.000	0.486	0.331	0.174	0.029	-0.071	-0.117	-0.099	-0.024	0.008	0.000	-0.035
1960	-0.109	-0.236	-0.337	-0.406	-0.541	-0.648	-0.701	-0.671	-0.596	-0.538	-0.488	-0.336
1961	-0.307	-0.441	-0.597	-0.713	-0.846	-0.904	-0.906	-0.924	-0.163	0.015	0.000	0.000
1962	0.000	0.674	0.512	0.363	0.223	0.113	0.075	0.040	0.051	0.146	1.025	1.104
1963	1.056	0.947	0.833	0.675	0.557	0.476	0.432	0.425	1.122	1.433	0.000	0.000
1964	0.000	1.195	1.092	0.933	0.822	0.757	0.726	0.761	0.775	0.804	0.817	0.777
1965	0.716	0.598	0.459	0.294	0.153	0.043	0.040	0.048	0.055	0.181	0.404	0.642
1966	0.619	0.495	0.340	0.177	0.034	-0.064	0.864	0.962	1.622	1.872	2.542	0.000
1967	0.000	0.000	0.443	0.299	0.167	0.051	-0.001	0.017	0.097	0.141	0.436	0.495
1968	0.485	0.376	0.218	0.079	-0.057	-0.172	-0.168	-0.189	-0.157	-0.155	-0.156	-0.194
1969	-0.230	-0.355	-0.519	-0.685	-0.801	-0.933	-1.009	-1.011	-0.947	-0.870	-0.805	-0.779
1970	-0.749	-0.866	-1.006	-1.175	-1.314	-1.430	-1.468	-1.466	-1.414	-1.323	-0.638	-0.499
1971	-0.502	-0.612	-0.736	-0.895	-1.026	-1.129	-1.138	-1.107	-1.072	-1.059	-0.597	-0.377
1972	-0.389	-0.516	-0.667	-0.833	-0.983	-1.106	-1.174	-1.151	-1.146	-1.108	-1.111	-1.119
1973	-1.194	-1.297	-1.440	-1.599	-1.740	-1.859	-1.938	-1.862	-1.842	-1.843	1.904	2.475
1974	0.000	0.000	0.000	0.450	0.299	0.178	0.135	0.187	0.193	0.262	0.892	0.992
1975	1.071	0.961	0.795	0.620	0.482	0.383	0.434	0.450	0.000	0.000	0.000	0.895
1976	1.046	1.148	1.005	0.837	0.773	0.667	0.633	0.726	1.002	0.000	0.000	0.000
1977	0.610	0.516	0.454	0.301	0.177	0.087	0.049	0.041	0.038	0.256	0.577	0.715
1978	0.719	0.597	0.476	0.336	0.734	0.647	0.572	0.643	0.764	0.962	1.207	1.295
1979	1.609	1.502	1.364	1.212	1.078	0.946	0.900	0.923	0.988	0.970	0.972	0.939
1980	0.891	0.918	0.798	0.786	0.684	0.605	0.690	0.683	0.694	1.511	2.435	0.000
1981	0.000	0.000	0.454	0.308	0.163	0.066	0.773	0.839	0.946	0.945	1.007	1.020
1982	0.955	0.831	0.681	0.520	0.470	0.385	0.337	1.168	1.956	0.000	0.000	0.000
1983	0.667	0.584	0.429	0.261	0.127	0.025	-0.009	0.527	0.599	0.684	0.708	0.857
1984	1.094	0.970	0.855	0.770	0.660	0.559	0.570	0.546	0.572	0.000	0.000	0.000
1985	0.721	0.621	0.463	0.293	0.164	0.096	0.049	0.017	0.038	0.076	0.000	0.000
1986	0.000	0.539	0.390	0.233	0.105	-0.016	-0.010	0.027	0.058	0.079	0.567	1.004
1987	1.045	0.914	0.779	0.607	0.479	0.360	0.419	0.431	0.481	0.493	0.561	0.660
1988	0.666	0.545	0.398	0.241	0.112	0.334	2.036	2.159	0.000	0.000	0.000	2.094
1989	2.501	2.413	2.256	2.103	2.003	1.886	2.062	2.455	0.000	0.000	0.000	0.753
1990	0.701	0.590	0.438	0.290	0.142	0.029	-0.035	0.001	0.064	1.890	2.060	2.194
1991	0.000	0.000	0.000	0.444	0.322	0.214	0.195	0.239	0.355	0.387	0.686	1.222
1992	1.863	1.858	1.716	1.557	1.463	1.346	0.000	0.000	0.000	0.000	2.227	2.511
1993	2.444	2.328	2.210	2.054	1.921	1.807	1.793	1.804	0.000	0.000	0.000	0.745
1994	0.740	0.614	0.559	0.416	0.275	0.293	0.278	0.483	0.594	0.940	2.127	2.357
1995	2.400	2.305	2.353	2.197	2.081	1.970	1.899	1.881	1.932	2.055	2.185	2.397
1996	0.000	0.000	0.000	0.443	0.310	0.186	0.157	0.866	1.206	1.293	1.481	1.515
1997	1.485	1.555	1.401	1.251	1.108	1.014	1.069	0.000	0.000	0.000	0.941	1.062
1998	0.987	1.283	0.000	0.000	0.000	0.479	0.483	0.486	0.491	0.482	0.594	1.201
1999	1.212	1.092	0.958	0.829	0.683	0.643	0.591	0.601	0.613	0.659	0.684	0.704
2000	0.634	0.506	0.361	0.205	0.065	-0.059	-0.100	-0.090	-0.096	0.539	1.193	1.478
2001	1.588	1.488	1.341	1.365	1.255	1.133	1.106	1.131	1.260	1.934	0.000	0.000
2002	0.000	0.485	0.325	0.182	0.045	2.313	2.276	2.405	2.405	2.416	0.000	0.000
2003	0.000	0.473	0.338	0.197	0.065	-0.041	-0.085	-0.114	-0.080	-0.007	0.003	-0.024
2004	1.283	1.235	1.093	0.995	0.858	0.736	0.000	0.000	0.000	0.818	1.101	1.245

Table 5.10. Klein Estuary simulated average monthly water level (m to MSL) under Scenario 5. Colour coding indicates likley occurrence of different abiotic states as follows: State 1: Open marine, 2: Open gradient, 3: Closed marine, 4: Closed brakish, 5: Closed hypersaline.

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.587	0.486	0.365	0.219	0.112	-0.006	-0.059	-0.091	0.000	0.000	0.000	1.028
1921	0.996	0.869	0.748	0.681	0.546	0.483	0.425	0.414	0.567	0.555	0.929	0.931
1922	0.870	2.507	2.368	2.238	2.089	1.970	2.074	2.521	0.000	0.000	0.000	0.812
1923	0.840	1.893	1.738	1.588	1.457	1.360	1.307	1.261	1.669	1.686	2.481	0.000
1924	0.000	0.000	0.464	0.324	0.181	0.060	0.005	-0.040	0.000	0.000	0.000	0.730
1925	0.833	0.730	0.581	0.411	0.278	0.168	0.106	0.115	0.144	1.119	1.375	1.458
1926	0.000	0.000	0.000	0.434	0.316	0.200	0.143	0.178	0.172	0.163	0.203	0.163
1927	0.085	-0.005	-0.131	-0.275	-0.417	-0.519	-0.596	-0.633	-0.594	-0.616	-0.597	-0.582
1928	-0.663	-0.742	-0.885	-1.056	-1.191	-1.283	-1.325	-1.326	-1.323	-1.205	-1.188	-1.228
1929	-1.304	-1.395	-1.522	-1.671	-1.776	-1.844	-1.879	-1.850	-1.844	-1.834	-1.783	-1.740
1930	-1.788	-1.871	-2.027	-2.189	-2.328	-2.437	-2.374	-2.367	-2.373	-2.320	-2.263	-2.081
1931	-1.331	-1.444	-1.582	-1.734	-1.831	-1.949	-2.024	-1.982	-1.934	-1.903	-1.900	-0.016
1932	0.168	0.048	-0.092	-0.258	-0.398	-0.506	-0.567	-0.560	-0.455	-0.368	1.390	1.586
1933	1.524	1.408	1.242	1.073	0.933	0.822	0.740	0.726	0.713	0.758	0.894	1.134
1934	1.297	1.179	1.019	0.857	0.713	0.603	0.595	0.656	0.743	0.753	0.732	0.727
1935	0.657	0.555	0.417	0.306	0.176	0.058	-0.002	0.038	0.061	0.102	0.114	0.102
1936	0.045	-0.040	-0.147	-0.302	-0.445	-0.535	-0.581	-0.607	-0.501	-0.044	0.160	0.503
1937	0.534	0.425	0.285	0.143	-0.001	-0.036	-0.042	-0.005	0.024	0.065	0.108	1.419
1938	1.737	1.638	1.486	1.321	1.228	1.154	1.132	1.128	1.116	1.186	1.317	1.309
1939	1.241	1.128	0.988	0.828	1.765	1.920	2.073	2.071	2.456	2.563	2.562	0.000
1940	0.000	0.000	0.442	0.287	0.143	0.019	0.258	1.122	1.886	2.585	0.000	0.000
1941	0.000	0.508	0.376	0.227	0.081	-0.030	-0.083	0.016	0.273	0.340	0.436	0.506
1942	0.441	0.321	0.219	0.615	0.501	0.418	0.391	0.403	0.417	0.471	0.531	0.618
1943	0.602	0.536	0.389	0.231	0.080	-0.042	-0.097	-0.020	1.640	1.783	0.000	0.000
1944	0.000	0.498	0.354	0.182	0.031	-0.090	-0.118	0.000	0.000	0.000	0.000	1.123
1945	2.058	2.070	1.930	1.772	1.631	1.589	1.533	1.535	1.578	1.597	1.607	1.682
1946	1.647	1.519	1.366	1.196	1.053	0.979	0.933	0.939	0.943	1.100	1.134	1.110
1947	1.049	0.945	0.788	0.630	0.486	0.460	0.437	0.432	0.483	0.536	0.520	0.521
1948	0.000	0.000	0.000	0.446	0.305	0.177	0.178	0.226	0.241	0.269	0.344	0.342
1949	0.287	0.241	0.095	-0.074	-0.224	-0.348	-0.353	-0.368	-0.363	-0.283	-0.297	-0.273
1950	-0.321	-0.370	-0.488	-0.586	-0.724	-0.825	-0.795	-0.766	0.997	0.000	0.000	0.000
1951	1.045	0.946	0.788	0.626	0.491	0.374	0.331	0.353	0.386	0.438	0.667	1.728
1952	1.971	0.000	0.000	0.000	0.461	0.336	0.368	0.392	0.453	0.546	0.562	0.531
1953	0.466	0.387	0.230	0.066	-0.063	-0.161	-0.168	1.348	1.889	0.000	0.000	0.000
1954	0.574	0.479	0.333	0.169	1.929	1.864	1.814	1.792	1.839	2.578	0.000	0.000
1955	0.000	0.501	0.356	0.188	0.061	-0.023	-0.069	0.407	1.276	1.622	0.000	0.000
1956	0.000	0.473	0.406	0.246	0.137	0.047	0.013	1.370	0.000	0.000	0.000	1.467
1957	0.000	0.000	0.000	0.428	0.320	0.252	0.225	1.411	1.604	1.601	0.000	0.000
1958	0.000	0.488	0.331	0.186	0.048	-0.040	1.078	1.891	1.935	2.020	0.000	0.000
1959	0.000	0.481	0.326	0.169	0.023	-0.077	-0.122	-0.104	-0.029	0.003	-0.005	-0.040
1960	-0.115	-0.241	-0.342	-0.411	-0.547	-0.654	-0.706	-0.677	-0.601	-0.544	-0.493	-0.467
1961	-0.516	-0.651	-0.807	-0.923	-1.055	-1.114	-1.115	-1.133	-0.994	-0.954	0.000	0.000
1962	0.000	0.630	0.469	0.319	0.179	0.069	0.032	-0.004	0.007	0.102	0.649	0.693
1963	0.643	0.534	0.419	0.262	0.144	0.063	0.019	0.012	0.374	0.659	2.329	0.000
1964	0.000	0.000	0.481	0.322	0.211	0.146	0.115	0.150	0.164	0.193	0.206	0.166
1965	0.105	-0.013	-0.152	-0.316	-0.458	-0.568	-0.571	-0.563	-0.556	-0.430	-0.255	-0.219
1966	-0.284	-0.407	-0.563	-0.726	-0.869	-0.967	-0.757	-0.689	-0.046	0.177	0.817	0.976
1967	0.961	0.863	0.706	0.562	0.429	0.313	0.261	0.280	0.360	0.404	0.467	0.439
1968	0.401	0.292	0.134	-0.005	-0.141	-0.256	-0.252	-0.273	-0.241	-0.239	-0.240	-0.278
1969	-0.314	-0.439	-0.603	-0.769	-0.885	-1.017	-1.093	-1.095	-1.031	-0.954	-0.889	-0.884
1970	-0.926	-1.042	-1.183	-1.352	-1.491	-1.606	-1.645	-1.643	-1.591	-1.499	-1.428	-1.436
1971	-1.498	-1.607	-1.732	-1.891	-2.022	-2.125	-2.133	-2.102	-2.068	-2.055	-1.990	-1.976
1972	-2.049	-2.176	-2.328	-2.494	-2.643	-2.700	-2.700	-2.700	-2.700	-2.700	-2.700	-2.700
1973	-2.700	-2.700	-2.700	-2.700	-2.700	-2.700	-2.700	-2.624	-2.604	-2.604	0.343	0.884
1974	1.102	0.978	0.819	0.668	0.518	0.397	0.354	0.406	0.412	0.480	0.742	0.808
1975	0.853	0.742	0.576	0.402	0.264	0.164	0.216	0.231	0.000	0.000	0.000	0.862
1976	0.976	1.040	0.897	0.729	0.664	0.559	0.525	0.618	0.715	0.000	0.000	0.000
1977	0.570	0.476	0.413	0.261	0.137	0.047	0.009	0.001	-0.002	0.216	0.318	0.347
1978	0.303	0.181	0.060	-0.080	0.109	0.021	-0.053	0.003	0.056	0.195	0.412	0.467
1979	0.752	0.644	0.507	0.354	0.220	0.088	0.043	0.065	0.131	0.112	0.115	0.082
1980	0.033	0.061	-0.060	-0.071	-0.174	-0.252	-0.167	-0.174	-0.163	-0.057	0.841	1.433
1981	1.465	1.365	1.218	1.073	0.928	0.831	1.293	1.325	1.407	1.406	1.436	1.437
1982	1.372	1.249	1.098	0.937	0.888	0.802	0.754	1.228	1.998	0.000	0.000	0.000
1983	0.626	0.542	0.387	0.220	0.086	-0.017	-0.051	0.206	0.249	0.307	0.299	0.418
1984	0.621	0.496	0.382	0.296	0.186	0.086	0.097	0.072	0.098	2.456	0.000	0.000
1985	0.000	0.500	0.342	0.172	0.042	-0.025	-0.072	-0.104	-0.083	-0.045	0.000	0.000
1986	0.000	0.539	0.390	0.233	0.105	-0.016	-0.010	0.027	0.058	0.079	0.218	0.625
1987	0.625	0.494	0.359	0.187	0.059	-0.060	-0.002	0.011	0.061	0.073	0.141	0.139
1988	0.095	-0.025	-0.172	-0.329	-0.458	-0.434	0.960	1.052	2.116	0.000	0.000	0.000
1989	0.974	0.860	0.703	0.551	0.450	0.333	0.372	0.629	1.939	0.000	0.000	0.000
1990	0.529	0.418	0.266	0.118	-0.030	-0.142	-0.207	-0.171	-0.108	1.357	1.494	1.598
1991	2.317	2.261	2.118	1.961	1.839	1.732	1.712	1.757	1.873	1.905	1.962	2.392
1992	0.000	0.000	0.000	0.441	0.347	0.231	0.000	0.000	0.000	0.000	2.199	2.447
1993	2.370	2.254	2.136	1.980	1.847	1.733	1.719	1.730	0.000	0.000	0.000	0.712
1994	0.670	0.544	0.490	0.346	0.205	0.223	0.209	0.269	0.309	0.533	1.692	1.890
1995	1.896	1.801	1.766	1.610	1.494	1.383	1.312	1.294	1.344	1.467	1.504	1.549
1996	0.000	0.000	0.000	0.443	0.310	0.186	0.157	0.625	0.942	0.997	1.159	1.157
1997	1.125	1.120	0.966	0.816	0.673	0.579	0.634	0.000	0.000	0.000	0.912	0.998
1998	0.923	1.149	0.000	0.000	0.000	0.479	0.483	0.486	0.491	0.482	0.594	0.894
1999	0.865	0.745	0.610	0.481	0.336	0.295	0.244	0.253	0.265	0.312	0.337	0.357
2000	0.287	0.159	0.014	-0.143	-0.282	-0.406	-0.447	-0.437	-0.444	-0.314	0.081	0.336
2001	0.410	0.310	0.163	0.165	0.055	-0.067	-0.094	-0.069	0.048	0.433	1.444	1.809
2002	1.834	1.719	1.559	1.415	1.279	0.000	0.000	0.000	0.600	0.611	0.000	0.000
2003	0.000	0.473	0.338	0.197	0.065	-0.041	-0.085	-0.114	-0.080	-0.007	0.003	-0.024
2004	0.852	0.763	0.621	0.523	0.387	0.265	0.000	0.000	0.000	0.786	1.042	1.153

Table 5.11. Klein Estuary simulated average monthly water level (m to MSL) under Scenario 6. Colour coding indicates likley occurrence of different abiotic states as follows: State 1: Open marine, 2: Open gradient, 3: Closed marine, 4: Closed brakish, 5: Closed hypersaline.

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.587	0.486	0.365	0.219	0.112	-0.006	-0.059	-0.091	0.000	0.000	0.000	1.007
1921	0.944	0.817	0.696	0.629	0.495	0.432	0.374	0.362	0.409	0.397	0.605	0.581
1922	0.520	2.105	1.967	1.836	1.687	1.569	1.673	1.948	2.376	0.000	0.000	0.000
1923	0.602	1.626	1.471	1.321	1.190	1.093	1.040	0.994	1.197	1.214	1.971	2.125
1924	2.078	2.095	1.959	1.819	1.676	1.555	1.501	1.455	0.000	0.000	0.000	0.703
1925	0.780	0.677	0.528	0.358	0.225	0.115	0.053	0.062	0.091	0.816	1.050	1.109
1926	0.000	0.000	0.000	0.434	0.316	0.200	0.143	0.178	0.172	0.163	0.203	0.163
1927	0.085	-0.005	-0.131	-0.275	-0.417	-0.519	-0.596	-0.633	-0.594	-0.616	-0.597	-0.582
1928	-0.663	-0.742	-0.885	-1.056	-1.191	-1.283	-1.325	-1.326	-1.323	-1.205	-1.188	-1.228
1929	-1.304	-1.395	-1.522	-1.671	-1.776	-1.844	-1.879	-1.850	-1.844	-1.834	-1.783	-1.740
1930	-1.788	-1.871	-2.027	-2.189	-2.328	-2.437	-2.374	-2.367	-2.373	-2.320	-2.263	-2.270
1931	-2.241	-2.363	-2.501	-2.653	-2.700	-2.700	-2.700	-2.700	-2.700	-2.700	-2.700	-1.530
1932	-1.373	-1.494	-1.634	-1.799	-1.940	-2.048	-2.108	-2.101	-1.997	-1.952	-0.427	-0.256
1933	-0.319	-0.435	-0.600	-0.769	-0.909	-1.021	-1.102	-1.117	-1.129	-1.085	-0.948	-0.887
1934	-0.901	-1.019	-1.178	-1.340	-1.484	-1.595	-1.603	-1.542	-1.455	-1.445	-1.466	-1.471
1935	-1.541	-1.643	-1.780	-1.891	-2.022	-2.139	-2.200	-2.160	-2.136	-2.095	-2.084	-2.096
1936	-2.152	-2.237	-2.345	-2.500	-2.700	-2.700	-2.700	-2.700	-2.594	-2.347	-2.305	-2.276
1937	-2.324	-2.433	-2.573	-2.700	-2.700	-2.700	-2.700	-2.700	-2.700	-2.659	-2.616	-1.746
1938	-1.452	-1.552	-1.704	-1.868	-1.962	-2.035	-2.058	-2.061	-2.073	-2.003	-1.872	-1.880
1939	-1.948	-2.061	-2.202	-2.361	-1.853	-1.728	-1.597	-1.599	-1.254	-1.169	-1.189	-1.174
1940	-1.237	-1.276	-1.434	-1.589	-1.734	-1.857	-1.675	-0.982	-0.239	0.442	1.446	0.000
1941	0.000	0.000	0.468	0.319	0.172	0.062	0.009	0.108	0.241	0.254	0.268	0.305
1942	0.240	0.120	0.017	0.299	0.185	0.102	0.075	0.086	0.101	0.154	0.215	0.233
1943	0.171	0.105	-0.043	-0.200	-0.352	-0.474	-0.529	-0.452	0.884	1.004	0.000	0.000
1944	0.000	0.498	0.354	0.182	0.031	-0.090	-0.118	0.000	0.000	0.000	0.000	1.097
1945	2.012	1.992	1.852	1.695	1.553	1.512	1.455	1.458	1.500	1.519	1.529	1.604
1946	1.569	1.442	1.288	1.119	0.976	0.902	0.855	0.862	0.865	1.022	1.056	1.032
1947	0.971	0.868	0.710	0.552	0.408	0.382	0.359	0.354	0.406	0.458	0.442	0.444
1948	2.049	2.353	2.219	2.065	1.924	1.796	1.797	1.844	1.860	1.888	1.962	1.961
1949	1.906	1.860	1.714	1.544	1.395	1.271	1.265	1.251	1.256	1.336	1.322	1.346
1950	1.298	1.249	1.131	1.032	0.894	0.793	0.823	0.853	1.818	0.000	0.000	0.000
1951	1.016	0.917	0.759	0.597	0.462	0.345	0.302	0.324	0.356	0.409	0.638	1.412
1952	1.627	2.574	2.433	2.276	2.136	2.011	2.043	2.067	2.128	2.221	2.238	2.207
1953	2.141	2.062	1.906	1.742	1.613	1.514	1.508	2.545	0.000	0.000	0.000	1.093
1954	1.049	0.953	0.807	0.643	2.255	2.190	2.140	2.118	2.165	0.000	0.000	0.000
1955	0.793	0.694	0.550	0.381	0.255	0.171	0.125	0.398	1.253	1.581	0.000	0.000
1956	0.000	0.473	0.406	0.246	0.137	0.047	0.013	1.172	0.000	0.000	0.000	1.446
1957	0.000	0.000	0.000	0.428	0.320	0.252	0.225	1.237	1.410	1.389	0.000	0.000
1958	0.000	0.488	0.331	0.186	0.048	-0.040	0.898	1.693	1.713	1.777	0.000	0.000
1959	0.000	0.481	0.326	0.169	0.023	-0.077	-0.122	-0.104	-0.029	0.003	-0.005	-0.040
1960	-0.115	-0.241	-0.342	-0.411	-0.547	-0.654	-0.706	-0.677	-0.601	-0.544	-0.493	-0.467
1961	-0.516	-0.651	-0.807	-0.923	-1.055	-1.114	-1.115	-1.133	-0.994	-0.954	2.439	0.000
1962	0.000	0.000	0.439	0.289	0.149	0.039	0.002	-0.034	-0.023	0.072	0.374	0.391
1963	0.341	0.232	0.118	-0.040	-0.158	-0.239	-0.283	-0.290	-0.074	0.087	1.738	2.023
1964	2.013	2.557	2.439	2.280	2.168	2.104	2.073	2.107	2.121	2.151	2.163	2.123
1965	2.063	1.944	1.806	1.641	1.499	1.389	1.387	1.394	1.401	1.527	1.703	1.738
1966	1.673	1.550	1.395	1.231	1.088	0.991	1.173	1.215	1.386	1.450	1.940	2.073
1967	2.031	1.933	1.776	1.632	1.499	1.383	1.331	1.350	1.430	1.474	1.537	1.509
1968	1.471	1.362	1.204	1.065	0.929	0.814	0.817	0.797	0.829	0.831	0.830	0.792
1969	0.756	0.631	0.467	0.301	0.185	0.053	-0.023	-0.025	0.039	0.116	0.181	0.186
1970	0.144	0.028	-0.113	-0.282	-0.421	-0.536	-0.575	-0.573	-0.521	-0.429	-0.359	-0.366
1971	-0.428	-0.537	-0.662	-0.821	-0.952	-1.055	-1.064	-1.032	-0.998	-0.985	-0.920	-0.906
1972	-0.979	-1.106	-1.258	-1.424	-1.573	-1.696	-1.764	-1.741	-1.736	-1.699	-1.701	-1.709
1973	-1.784	-1.887	-2.030	-2.189	-2.330	-2.450	-2.529	-2.453	-2.432	-2.433	-0.639	-0.120
1974	0.071	-0.053	-0.212	-0.363	-0.513	-0.634	-0.677	-0.625	-0.619	-0.551	-0.494	-0.523
1975	-0.521	-0.631	-0.797	-0.972	-1.110	-1.209	-1.158	-1.142	1.372	2.082	0.000	0.000
1976	0.000	0.636	0.492	0.325	0.260	0.155	0.120	0.214	0.311	2.275	0.000	0.000
1977	0.000	0.506	0.444	0.291	0.168	0.077	0.039	0.031	0.028	0.246	0.349	0.377
1978	0.334	0.212	0.090	-0.050	0.060	-0.028	-0.102	-0.045	0.007	0.054	0.077	0.060
1979	0.177	0.069	-0.068	-0.220	-0.355	-0.486	-0.532	-0.510	-0.444	-0.462	-0.460	-0.493
1980	-0.542	-0.514	-0.635	-0.646	-0.749	-0.827	-0.742	-0.749	-0.738	-0.653	-0.312	0.258
1981	0.260	0.159	0.013	-0.133	-0.278	-0.375	-0.094	-0.074	-0.017	-0.018	0.012	0.013
1982	-0.052	-0.176	-0.326	-0.487	-0.537	-0.622	-0.671	-0.500	0.255	1.073	1.553	2.081
1983	2.077	1.994	1.839	1.671	1.537	1.435	1.401	1.572	1.602	1.636	1.627	1.637
1984	1.752	1.627	1.513	1.427	1.318	1.217	1.228	1.204	1.229	0.000	0.000	0.000
1985	0.661	0.560	0.403	0.232	0.103	0.036	-0.011	-0.044	-0.023	0.016	0.000	0.000
1986	0.000	0.539	0.390	0.233	0.105	-0.016	-0.010	0.027	0.058	0.079	0.161	0.335
1987	0.306	0.174	0.039	-0.132	-0.260	-0.380	-0.321	-0.308	-0.258	-0.247	-0.178	-0.180
1988	-0.224	-0.345	-0.492	-0.648	-0.777	-0.753	0.152	0.222	1.270	0.000	0.000	0.000
1989	0.949	0.835	0.678	0.526	0.425	0.308	0.347	0.440	1.709	2.383	0.000	0.000
1990	0.000	0.489	0.337	0.188	0.041	-0.072	-0.136	-0.100	-0.037	1.154	1.267	1.349
1991	2.047	1.961	1.818	1.662	1.539	1.432	1.413	1.457	1.573	1.605	1.662	1.789
1992	2.380	2.300	2.157	1.999	1.905	1.788	0.000	0.000	0.000	0.000	2.177	2.400
1993	2.322	2.207	2.089	1.933	1.800	1.686	1.672	1.683	0.000	0.000	0.000	0.687
1994	0.646	0.519	0.465	0.321	0.180	0.198	0.184	0.245	0.285	0.363	1.397	1.571
1995	1.550	1.455	1.385	1.229	1.113	1.002	0.931	0.913	0.964	1.087	1.124	1.169
1996	2.009	2.142	2.017	1.860	1.728	1.603	1.574	1.865	2.165	2.196	2.338	2.309
1997	2.277	2.216	2.062	1.913	1.770	1.675	1.730	0.000	0.000	0.000	0.889	0.950
1998	0.875	1.048	0.000	0.000	0.000	0.479	0.483	0.486	0.491	0.482	0.594	0.738
1999	0.690	0.570	0.435	0.306	0.161	0.120	0.069	0.078	0.090	0.137	0.162	0.181
2000	0.112	-0.017	-0.161	-0.318	-0.457	-0.581	-0.623	-0.613	-0.619	-0.489	-0.368	-0.340
2001	-0.371	-0.470	-0.617	-0.616	-0.726	-0.848	-0.875	-0.850	-0.733	-0.628	0.311	0.655
2002	0.651	0.536	0.376	0.232	0.096	1.984	1.947	1.994	1.994	2.004	0.000	0.000
2003	0.000	0.473	0.338	0.197	0.065	-0.041	-0.085	-0.114	-0.080	-0.007	0.003	-0.024
2004	0.531	0.442	0.300	0.202	0.066	-0.056	0.000	0.000	0.000	0.763	0.997	1.084



	Reference	Present	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6
State 1: Open, marine	21	14	15	14	12	7	6	4
State 2: Open, gradient	9	8	10	10	6	6	5	4
State 3: Closed, marine	45	61	58	56	67	69	71	60
State 4: Closed, brackish	25	17	17	20	14	12	8	15
State 5: Closed, hypersaline	0	0	0	0	0	6	10	17

Figure 5.1. Occurrence of different abiotic states in the Klein estuary under the Reference and Present state and different operational scenarios.

A summary of changes in hydrodynamic conditions under the various scenarios is presented in Table 5.12. Health scores indicating changes in mouth condition, stratification, water retention time and water level and scores are summarised in Table 5.13.

Table 5.12. Summary of changes in hydrodynamic conditions under the varouis scenarios

<table>
<tr><th>Parameter</th><th>Summary of changes</th></tr>
<tr><td>a. Mouth condition & abiotic states</td><td>% open mouth conditions under the various scenarios:
<table>
<tr><th>Ref</th><th>Pres</th><th>Sc1</th><th>Sc2</th><th>Sc3</th><th>Sc4</th><th>Sc5</th><th>Sc6</th></tr>
<tr><td>30</td><td>22</td><td>25</td><td>23</td><td>19</td><td>13</td><td>11</td><td>8</td></tr>
</table></td></tr>
<tr><td>b. Stratification</td><td>Estimated average salinity difference between surface and bottom salinity in water column:
<table>
<tr><th></th><th>Ref</th><th>Pres</th><th>Sc1</th><th>Sc2</th><th>Sc3</th><th>Sc4</th><th>Sc5</th><th>Sc6</th></tr>
<tr><td>Zone A</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Zone B</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Zone C</td><td>3</td><td>2</td><td>2</td><td>2</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Zone D</td><td>7</td><td>5</td><td>5</td><td>6</td><td>4</td><td>3</td><td>2</td><td>4</td></tr>
</table></td></tr>
<tr><td>c. Water retention time</td><td>The % occurrence of closed mouth conditions were taken as indicative of retention time:
<table>
<tr><th>Ref</th><th>Pres</th><th>Sc1</th><th>Sc2</th><th>Sc3</th><th>Sc4</th><th>Sc5</th><th>Sc6</th></tr>
<tr><td>70</td><td>78</td><td>75</td><td>77</td><td>81</td><td>87</td><td>89</td><td>92</td></tr>
</table></td></tr>
<tr><td>d. Water level</td><td>Estimated average change in water level from Reference:
<table>
<tr><th>Prese</th><th>Sc 1</th><th>Sc 2</th><th>Sc 3</th><th>Sc 4</th><th>Sc 5</th><th>Sc 6</th></tr>
<tr><td>-0.10</td><td>-0.05</td><td>0.05</td><td>-0.01</td><td>-0.12</td><td>-0.15</td><td>-0.20</td></tr>
</table></td></tr>
</table>

Table 5.13. Similarity scores for hydrodynamics under the various operation scenarios relative to the Present state.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Conf
a. Mouth condition & abiotic states	72	84	78	62	43	37	28	L
b. Stratification	92	93	94	88	84	80	86	L
c. Water retention time	89	94	91	86	80	79	76	L
d. Water level	97	96	97	97	93	89	79	L
Hydrodynamics and mouth conditions score	72	84	78	62	43	37	28	**L**

5.2.3 Water quality

Scoring of future scenarios in respect of Salinity/DIN/DIP, Turbidity, DO and Toxic substances followed a similar approach as described for the Present State. Based on the above, the estimated changes in water quality (salinity, DIN, DIP, suspended solids and dissolved oxygen) in different zones under the different scenarios are presented in Table 5.14. Details on the change in the axial salinity gradient, DIN/DIP, suspended solids, dissolved oxygen, and toxic substances are provided in Table 5.14.

Table 5.14. Estimated changes in water quality in different zones of the Klein estuary under Reference, present, future scenarios

Zones in Estuary	Volume weighting for Zone	Estimated SALINITY based on distribution of abiotic states							
		Reference	Present	Sc 1	Sc 2	Sc 3	Sc 4*	Sc 5*	Sc 6*
A (lower)	0.25	28	29	30	29	30	30	32	34
B	0.45	28	29	30	29	30	30	32	34
C	0.20	27	29	29	28	29	30	31	34
D (upper)	0.10	19	21	21	21	22	24	25	27
Max salinity	-	35	35	35	35	<45	45-50	50-60	>60
Occurrence of State 5	-	0	0	0	0	0	6%	10%	17%

**Note: Average scores do not reflect the impact of hyper salinity events that occur under Scenarios 4 to 6.*

Zones in Estuary	Volume weighting for Zone	Estimated DIN concentration (µg/ℓ) based on distribution of abiotic states							
		Reference	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6
A (lower)	0.25	61	198	197	215	180	169	146	222
B	0.45	50	191	190	208	174	166	143	222
C	0.20	50	211	215	233	189	181	155	230
D (upper)	0.10	63	684	679	688	679	659	701	825

Zones in Estuary	Volume weighting for Zone	Estimated DIP concentration (µg/ℓ) based on distribution of abiotic states							
		Reference	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6
A (lower)	0.25	12	19	19	19	19	19	20	20
B	0.45	10	18	18	18	18	19	19	19
C	0.20	10	19	19	19	19	19	19	20
D (upper)	0.10	10	29	29	29	29	33	56	109

Zones in Estuary	Volume weighting for Zone	Estimated TURBIDITY (NTU) based on distribution of abiotic states							
		Reference	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6
A (lower)	0.25	10	12	12	12	11	11	11	12
B	0.45	10	12	12	12	11	11	11	12
C	0.20	10	12	12	12	11	11	11	12
D (upper)	0.10	10	12	12	12	11	11	11	12

Zones in Estuary	Volume weighting for Zone	Estimated DISSOLVED OXYGEN concentration (mg/ℓ) based on abiotic states							
		Reference	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6
A (lower)	0.25	7	5	6	6	5	5	5	5
B	0.45	7	6	6	6	6	6	6	6
C	0.20	7	5	5	5	5	5	5	5
D (upper)	0.10	6	4	4	4	4	4	4	3

Table 5.15 Expected changes in axial salinity gradient, DIN/DIP, turbidity, dissolved oxygen, and toxic substances in the Klein estuary under the present and future flow scenarios

Parameter	Summary of changes
1. Changes in longitudinal salinity gradient and vertical stratification	Scenario 1 to 3 similar to present. Hyper salinity (<45) start to develop in Scenario 4. Extreme hyper salinity (toxic levels) under Scenario 5 and 6.
2a. DIN/DIP in estuary	Marked increase in nutrient input from anthropogenic sources (e.g. agriculture and WWTW effluent) remains in the future scenarios.
2b. Turbidity in estuary	No marked increase in turbidity, only very slight increase in levels compared with Reference.
2c. DO in estuary	Increase in organic loading and nutrient input (causing eutrophication) from anthropogenic sources (e.g. agriculture and WWTW effluent) causes reduction in oxygen levels, especially in the upper reaches
2d. Toxic substances in estuary	Agriculture in the catchment (herbicides and pesticides) and urban development along banks (metals and hydrocarbons) introduces some toxic substances into the estuary - assume 80% similarity as for Present

Table 5.16 Summary of changes and calculation of the water quality health score.

Variable		Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Conf
1	**Salinity**								
	Similarity in salinity *(similarity score adjusted for hyper salinity)*	97	96	97	96	74 (94-20)	52 (92-40)	29 (89 – 50)	
2	**General water quality**								
a	DIN and DIP concentrations	56	56	55	57	57	59	51	M/L
b	Turbidity	92	92	91	94	94	96	93	M/L
c	Dissolved oxygen (mg/l)	90	91	90	90	90	90	89	M/L
d	Toxic substances	80	80	80	80	80	80	80	L
	Water quality score*	81	80	80	80	67	55	38	

*Score = (0.6 x S + 0.4 x min (a to d))

5.2.4 Physical habitat alteration

All assessments and scoring for the habitat variables for the scenarios were done similarly to those for the present day situation. Changes and scores are summarised in Table 5.17 and Table 5.18.

Table 5.17. Summary of changes in physical habitats under the different scenarios.

Parameter	Scenarios 1-6
a. Supratidal area and sediments	Very similar to present for Scenario 1 to 4, but loss of resetting floods will increase sediment stability in the supratidal habitat under Scenario 5 and 6.
b. Intertidal areas and sediments	Similar to present for Scenario 1 to 3, but loss of breaching events and resetting floods will result in additional infilling of intertidal area in Zone A and C under Scenario 4, 5 and 6.
c. Subtidal area and sediments	Similar to present for Scenario 1 to 3, but loss of breaching events and resetting floods will result in additional infilling in subtidal habitat in Zone A and C under Scenario 4, 5 and 6.
d. Estuary bathymetry/water volume	Similar to present for Scenario 1 to 3, but loss of breaching events and resetting floods will result in loss of water column habitat in Zone A and C under Scenario 4, 5 and 6.

Table 5.18. Similarity scores for physical habitats under different scenarios.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Conf
a. Supratidal area and sediments	65	65	65	65	65	55	50	L
b. Intertidal areas and sediments	80	85	80	75	65	60	50	L
c. Subtidal area and sediments	85	90	85	80	75	75	70	L
d. Estuary bathymetry/water volume	85	90	85	85	80	80	75	L
Physical habitat score*	**65**	**65**	**65**	**65**	**65**	**55**	**50**	**L**

*Score = min a to d

5.3 Biotic components

This section predicts the change in biotic characteristics of the Scenarios compared with the Reference Condition, providing an explanation of the causes of these changes and confidence in the predictions.

5.3.1 Microalgae

A summary of the expected changes under various scenarios for the microalgae component in the Klein Estuary is provided in Table 5.19. Marked increase in nutrient input from anthropogenic sources (e.g. agriculture and WWTW effluent) remains in the future scenarios.

The main parameters used to estimate these changes are summarised in Table 3.24. Health scores for the future scenarios are presented in Table 5.20.

Table 5.19 Summary of how the microalgae change relative to the Reference and/or Present condition under the different scenarios.

SCENARIO	SUMMARY OF CHANGES
1	In this scenario almost all baseflow would be restored (+20% MAR) however nutrient concentrations remain high leading to high microalgal biomass. The loss of intertidal habitat means less area for intertidal benthic microalgae to establish.
2	Similar to Scenario 1 with some of the baseflow restored to the estuary (+10% MAR). Microalgal abundance remains high due to increased nutrient input.
3	There is a 12% decrease in MAR from present (33% reduction from natural). The closed mouth marine state increases and the closed brackish state decreases. There is an increase in phytoplankton blooms due to an increase in the duration of mouth closure and the continued high nutrient input.
4	Increase in phytoplankton blooms due to an increase in the duration of mouth closure and the continued high nutrient input. Closed hypersaline state occurs for 6% of the time. Blooms of cyanobacteria or other salt tolerant groups can occur under these conditions. For Scenarios 4 to 6 reduced flooding due to dam construction would increase deposition of organics and fine sediment which would increase benthic microalgae growth.
5	Closed hypersaline state occurs for 10% of the time. In the upper reaches average salinity of 19 (reference conditions) increases to 25 ppt. During dry years the estuary will go hypersaline but microalgal biomass can remain high due to salt tolerant bloom forming species and the high nutrient inputs.
6	Closed hypersaline state occurs for 17% of the time. Similar situation to Scenario 5, microalgae blooms will become more problematic due to greater retention of nutrients as a result of extended closed mouth conditions. During dry years the estuary will go hypersaline resulting in cyanobacteria and diatom benthic microalgal mats that are tolerant of high salinity. Blooms of cyanobacteria could also occur in the water column as grazers are reduced due to the high salinity.

Table 5.20. Similarity scores of microalgae under the different scenarios.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Conf
Phytoplankton score								
1. Species richness	75	75	70	65	55	50	45	L
2. Abundance	65	65	60	55	45	40	35	L
3. Community composition	70	70	65	60	50	45	40	L
Benthic microalgae score								
1.Species richness	75	70	65	60	60	55	50	L
2.Abundance	65	60	60	55	50	45	40	L
3.Community composition	70	65	60	60	55	50	45	L
Microalgae health score	**65**	**60**	**60**	**55**	**45**	**40**	**35**	

5.3.2 Macrophytes

The main parameters used to estimate these changes are summarised in Table 5.21. Scores are summarised in Table 5.22.

Table 5.21. Summary of the main parameters used to estimate changes in the macrophyte community, expressed as percentage of present day. Estimates are from the other specialists.

SCENARIO	SUMMARY OF CHANGES
1	In this scenario almost all baseflow would be restored (+20% MAR). The lower salinity conditions in the middle / upper reaches of the estuary will restore some reeds to this area. Salt marsh will colonise highly saline floodplain that is presently unsuitable for growth. Macrophyte habitat lost to development and agriculture will not be restored and displacement of submerged macrophytes by macroalgae will remain similar to present due to high nutrient input. ⇧ reeds & sedges, salt marsh
2	Similar to Scenario 1 with some of the baseflow restored to the estuary (+10% MAR). Macrophyte species richness, abundance and community composition slightly improved from present condition. ⇧ reeds & sedges, salt marsh
3	There is a 12% decrease in MAR from present (33% reduction from natural). The closed mouth marine state increases and the closed brackish state decreases. Increase in macroalgae blooms due to an increase in the duration of mouth closure and the continued high nutrient input. Loss of submerged macrophytes due to shading. ⇩ submerged macrophytes ⇧macroalgae
4	State 5: closed, hypersaline conditions, which would not have occurred under natural conditions now occurs for 6% of the time. Persistence of high salinity will reduce macrophyte habitat and create more highly saline barren habitat. In the upper reaches average salinity of 19 (reference conditions) increases to 24 ppt. However during dry years the estuary will go hypersaline resulting in a loss of all macrophyte habitats. Increase in macroalgae blooms due to an increase in the duration of mouth closure and the continued high nutrient input.

SCENARIO	SUMMARY OF CHANGES
	⇩ reeds & sedges, salt marsh ⇩ submerged macrophytes ⇧macroalgae
5	Closed hypersaline state occurs for 10% of the time. Saline conditions will restrict the distribution of reeds and sedges. Reduction in large floods due to dam development will prevent resetting of the estuary. Infilling of intertidal habitat will increase macrophyte habitat, however salt marsh and reeds and sedges will become inundated during closed mouth conditions causing die-back. In the upper reaches average salinity of 19 (reference conditions) increases to 25 ppt. During dry years the estuary will go hypersaline resulting in a loss of all macrophyte habitats. ⇩reeds & sedges, salt marsh ⇩ submerged macrophytes ⇧macroalgae
6	Closed hypersaline state occurs for 17% of the time. Similar situation to Scenario 5, macroalgae blooms will become more problematic due to greater retention of nutrients as a result of extended closed mouth conditions. Submerged macrophytes will be limited. Saline penetration to the upper reaches will reduce reed and sedge habitat. Distribution of salt marsh and reeds and sedges restricted by development and agriculture as well as the steep northern bank slopes. Increase in saline bare ground. In the upper reaches average salinity of 19 (reference conditions) increases to 27 ppt. During dry years the estuary will go hypersaline resulting in a loss of all macrophyte habitats. ⇩ reeds & sedges, salt marsh ⇩ submerged macrophytes ⇧macroalgae

Table 5.22. Similarity scores of macrophytes under the different scenarios.

VARIABLE	SCENARIO							
	PRESENT	1	2	3	4	5	6	CONF
a. Species richness	80	85	82	70	60	50	40	M
b Abundance	70	80	75	60	50	40	30	M
c. Community composition	81	90	85	70	60	50	40	M
Macrophyte score min (a to c)	70	80	75	60	50	40	30	

5.3.3 Invertebrates

A summary of the expected changes under various scenarios for the invertebrate component in the Klein Estuary is provided in Table 5.23. Health scores for the various operational scenarios are presented in Table 5.24.

Table 5.23. Summary of how the invertebrates change under the different scenarios.

Scenario	Summary of changes
Scenario 1	In this scenario, almost all baseflow would be restored (+20% MAR). The lower salinity conditions in the middle/upper reaches of the estuary will eliminate low salinity intolerant species, however, categories 1, 3, 4, 8 and 19 have wide salinity tolerance ranges and are able to tolerate low salinity values (<10) but their abundances would be affected by the duration of low salinity regimes. If salinity falls too low, breeding will probably cease until conditions become more favourable again. A slight increase in open marine mouth state would favour marine dominated species in the lower reaches such as categories 2, 5, 9, 11, 12, 18, 20, 21, 22. Increased benthic microalgal biomass will favour taxa such as categories 3 and 4. The loss of intertidal habitat would result in a proportional loss of intertidal invertebrates.
Scenario 2	Similar to Scenario 1 with some of the baseflow restored to the estuary (+10% MAR). Increased benthic microalgal biomass will favour taxa such as categories 3 and 4. The loss of intertidal habitat would result in a proportional loss of intertidal invertebrates.
Scenario 3	There is a 12% decrease in MAR from present (33% reduction from natural). The closed mouth marine state increases and the closed brackish state decreases. The increase in macroalgae would be detrimental to all intertidal benthic invertebrate macrofauna – *Callichirus kraussi* abundance and biomass will decrease and favour other species such as *Exosphaeroma, Cyathura estuaria* and *Talorchestia* who all favour vegetated areas. Increased mouth closure leads to decrease in species richness (absence of marine associated species). Open mouth linked to increased salinity values and opportunity for euryhaline species (category 2, 4, 5, 9, 11, 12, 13, 16, 17, 18) to increase in biomass and abundance if salinity increases from a low base (<10). An open mouth is also important for the input of larvae into the estuary from the marine environment for recruitment and vice versa.
Scenario 4	Closed, hypersaline conditions, which would not have occurred under natural conditions now occur for 6% of the time. Persistence of high salinity and mouth closure will reduce species richness, biomass and abundance as a result of mortality and reduced input of larvae into the estuary from the marine environment for recruitment and vice versa. Increases in macroalgae biomass will be detrimental to intertidal benthic invertebrate macrofauna.
Scenario 5	Closed hypersaline state occurs for 10% of the time. Saline conditions will result in mortality of estuarine species intolerant of increased salinity (categories 1, 3, 8, 10, and 19). Marine zooplankton (category 18) would initially increase with increased phytoplankton biomass but would later decrease under hypersaline conditions and reduced larval input from prolonged mouth closure. The extreme increase in macroalgae would be highly detrimental to intertidal benthic invertebrate macrofauna resulting in a major shift in the overall estuary community structure. During dry periods, the estuary will go hypersaline resulting in mass mortality of invertebrate fauna.
Scenario 6	Closed hypersaline state occurs for 17% of the time. Similar to Scenario 5. Extreme increase in macroalgae would lead to a decrease in abundance, biomass and diversity of intertidal benthic invertebrate macrofauna with hypoxic conditions in the underlying sediment causing mass mortalities. Species such as *Exosphaeroma, Cyathura estuaria* and *Talorchestia* would respond positively to the increase in available macroalgae food. Expect a major shift in the overall

	estuary community structure. During dry periods the estuary will go hypersaline resulting in mass mortalities of invertebrate fauna.

Table 5.24. Similarity scores for invertebrates under the different scenarios.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Conf
1. Species richness	80	98	95	65	60	55	45	M
2. Abundance	75	95	90	60	55	50	40	L
3. Biomass	70	95	90	55	50	40	30	L
4. Community composition	70	95	90	55	50	40	30	L
Invertebrate score	**70**	**95**	**90**	**55**	**50**	**40**	**30**	**L**

5.3.4 Fish

A summary of the expected changes under various scenarios for the invertebrate component in the Klein Estuary is provided in Table 5.25. Health scores for the various operational scenarios are presented in Table 5.26.

Table 5.25. Summary of how the fish change under the different scenarios.

Scenario	Summary of changes
Scenario 1	Slight⇧ mouth opening, ⇧recruitment. ⇧ microalgal biomass, ⇩dissolved oxygen (mg/l), ⇧night-time stress. ⇩ *C. spatulatus, S. temminckii, Caffrogobius* macrophyte habitat , ⇩benthic microalgae, ⇩Mugillidae
Scenario 2	Mouth closure⇧ similar to present, = recruitment similar, high microalgal biomass,⇩oxygen (mg/l), ⇧nightime stress. Slight ⇧*C. spatulatus, S. temminckii, Caffrogobius* macrophyte habitat ⇩benthic microalgae, ⇩Mugillidae
Scenario 3	Mouth closure⇧19% open, probability of recruitment 37% ⇩ from reference, ⇧phytoplankton blooms, dissolved oxygen (mg/l) ⇩, ⇧fish, algal toxicity, ⇧susceptibility to invasive pathogens , ⇩ *C. spatulatus, S. temminckii, Caffrogobius* macrophyte habitat , ⇩benthic microalgae, ⇩Mugillidae
Scenario 4	Mouth closure⇧13% open, recruitment 57% ⇩ from reference, hypersalinity, ⇧ susceptibility to low oxygen, ⇧phytoplankton blooms, dissolved oxygen (mg/l) ⇩, ⇧fish kills, algal toxicity, ⇧susceptibility to infections of invasive pathogens, ⇩ *C. spatulatus, S. temminckii, Caffrogobius* macrophyte subtidal habitat⇩benthic microalgae, ⇩Mugillidae
Scenario 5	Mouth closure⇧11% open, recruitment 63% ⇩ from reference, ⇧⇧hypersalinity, ⇧ susceptibility to low oxygen, ⇧phytoplankton blooms, dissolved oxygen (mg/l) ⇩, ⇧fish kills, algal toxicity, ⇧susceptibility to invasive pathogens. Loss of macrophyte subtidal habitat. *O. mossambicus* expands into lower reaches of estuary. Most estuary-dependent marine species lost from the estuary. ⇩benthic microalgae, ⇩Mugillidae
Scenario 6	Mouth closure⇧8% open, recruitment 74% ⇩ from reference, ⇧⇧hypersalinity, ⇧ susceptibility to low oxygen, ⇧phytoplankton blooms, dissolved oxygen (mg/l) ⇩, ⇧fish kills from low oxygen levels, algal toxicity or ⇧susceptibility to invasive pathogens. Loss of macrophyte subtidal habitat. *O. mossambicus* expands into lower reaches of estuary. Most estuary-dependent marine species lost from the estuary. ⇩benthic microalgae, ⇩Mugillidae

Table 5.26. Similarity scores for fish under the different scenarios.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Conf
1. Species richness	80	80	80	75	60	60	60	M
2 Abundance	60	65	60	60	50	40	40	M
3. Community composition	70	70	70	65	50	40	35	M
Fish score (min 1-3)	**60**	**65**	**60**	**60**	**50**	**40**	**35**	

5.3.5 Birds

Changes in the main parameters used to estimate changes in Bird communities are summarised in Table 5.27. Health scores for the Bird community under the future scenarios are presented in Table 5.28.

Table 5.27. Summary of the main parameters used to estimate changes in the bird community, expressed as percentage of present day. Estimates are from the other specialists.

Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Flows	77	98	93	75	67	59
Mouth	73	83	77	63	43	37
Intertidal area and sediments	80	80	80	80	80	80
Salinity (lower score = saltier)	97	96	97	96	74	52
Reeds, sedges & submerged macrophytes	70	80	75	60	50	40
Intertidal Saltmarsh	70	70	70	70	70	70
Microalgae	135	137.5	140	145	152.5	157.5
Invertebrates	60	80	75	55	45	25
Fish abundance	60	65	60	60	50	40

Table 5.28. Summary of how the birds change under the different scenarios.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Conf
1. Species richness	90	95	95	90	85	80	75	L
2 Abundance **(min)**	**21**	**23**	**22**	**19**	**16**	**12**	**9**	L
3. Community composition	34	36	35	32	27	22	17	L
Bird score (min 1-3)	**21**	**23**	**22**	**19**	**16**	**12**	**9**	**L**

5.4 Ecological Categories associated with runoff scenarios

A summary of the Habitat, Biotic and overall Estuary Health scores for each of the scenarios evaluated in this study are presented in Table 5.29. Under Present day conditions the health of the Klein estuary is rated as 62% overall ("C" class). Health improves slightly under Scenarios 1 and 2 (score 65 and 61, respectively), which allow for an increase in runoff to the estuary (20% and 10%, respectively) but the health class does not change. Health declines under all of the other operation scenarios, dropping to a "D" Class for Scenarios 3-5 and an "E" Class for Scenario 6 (Table 5.1. Importantly, the reduction in the health status of the estuary under Present Day conditions and under the operational scenarios, is attributable to non-flow related anthropogenic interventions. The health status of the system under Present Day conditions is expected to increase to 83% (a "B" class) if all non-flow related impacts could be eliminated, without any change in the quantities of freshwater received. The health status under the remaining scenarios also increase dramatically if non-flow related impacts are removed, increasing to 88% under Scenario 1, 86% under Scenario 2, and 69-80% for Scenarios 3-6. In an ideal world one would seek to remove all non-flow related impacts and restore all of the natural runoff to the system to return it to a pristine state. Recognising that this is not possible in the real world, certain trade-off must be made in order to restore the estuary into the best possible state based on the conservation priorities and importance of the system which must be traded off against other existing and potential future water requirements. These trade-offs are discussed in the next section (Section 6).

Table 5.29. EHI score and corresponding Ecological Category under the different runoff scenarios

	Wt	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Conf
Hydrology	25	77	98	93	75	67	59	53	M
Hydrodynamics and mouth condition	25	72	84	78	62	43	37	28	L
Water quality	25	81	80	80	80	67	55	38	M/L
Physical habitat alteration	25	65	65	65	65	65	55	50	L
Habitat health score		**68**	**74**	**72**	**65**	**58**	**51**	**40**	**L**
Microalgae	20	65	60	60	55	45	40	35	L
Macrophytes	20	70	80	75	60	50	40	30	M
Invertebrates	20	70	95	90	55	50	40	30	L
Fish	20	60	65	60	60	50	40	35	M
Birds	20	21	23	22	19	16	12	9	
Biotic health score		**57**	**65**	**61**	**50**	**42**	**34**	**28**	**L**
ESTUARY HEALTH SCORE		**65**	**72**	**70**	**60**	**51**	**43**	**35**	**L**
ECOLOGICAL STATUS		**C**	**C**	**C**	**D**	**D**	**D**	**E**	
EHI after non-flow impacts removed		**91**	**94**	**94**	**90**	**86**	**84**	**81**	
PES after non-flow impacts removed		**A**	**A**	**A**	**B**	**B**	**C**	**C**	

6 RECOMMENDATIONS

6.1 Recommended ecological flow requirements for the Klein estuary

In accordance with the manual for determining environmental flows for estuaries (DWA 2012), in the case of a high confidence study, the **'recommended Ecological Flow Requirement' scenario,** is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the recommended Ecological Category. Where any component of the health score is less than 40, then modifications to flow and measures to address anthropogenic impacts must be found that will rectify this. For lower confidence studies, such as this one, a more conservative flow scenario (or a slight modification thereof to address low-scoring components) should be chosen, using the guidelines in Table 6.1 (DWA 2012).

Table 6.1. Guidelines for identification of the recommended Ecological Flow Requirement' scenario. From DWA (2012)

Overall confidence	Choice of recommended ecological flow requirement' scenario
Very Low (rough estimate) <40% certain	The scenario with the lowest change in river inflow that will maintain the estuary in the recommended Ecological Category or obtain a health score that is one class higher (large safety buffer).
Low <40 - 60% certain	The scenario with the highest change in river inflow that will maintain the estuary in the recommended Ecological Category or obtain a health score that is one class higher (large safety buffer)
Medium 60-80% certain	The scenario with the highest change in river inflow that will maintain the estuary in the recommended Ecological Category or obtain a health score that is half a class higher (small safety buffer)
High >80% certain	The scenario with the highest change in river inflow that will still maintain the estuary in the recommended Ecological Category (no safety buffer)

Based on this assessment, the Best Attainable State for the Klein estuary is a B (one class higher than Present). Attaining this state would require restoring a certain amount of flow to the system as well as addressing some of the existing non-flow related issues affecting the estuary.

Two scenarios were considered in this study in which flows to the Klein estuary were restored towards natural – Scenario 1 and 2 (Table 5.1). Scenario 1 entailed increasing Present Day flows by 20% - i.e. restoring flows to within 97.5% of Natural. This would require removing all Invasive Alien Plants (AIPs) from the catchment and reducing irrigation use by 46%. This is unfortunately not considered feasible. Scenario 2 is more realistic as it entailed increasing flows relative to Present Day by 10% - i.e. to within 92.6% of Natural. This could be achieved by removing all AIPs from the catchment or by removing the majority of these AIPs and through modest improvements in irrigation efficiency and/or eliminating some illegal use. This is considered to be entirely feasible.

Thus, it was agreed that the flow requirements for the estuary are the same as those described for Scenarios 2. A summary of the monthly flows for these two scenarios is presented in Table 6.2.

Table 6.2. Summary of the monthly flow (distribution in Mm^3) under Scenario 2.

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	31.86996	15.85168	6.82348	3.78748	16.33256	10.99668	62.07284	33.07472	52.09756	50.2228	60.37216	50.09532
90%ile	8.2754	3.933	0.638	0.1666	0.1362	0.3282	3.728	10.6746	14.8056	22.8882	31.644	9.7088
80%ile	4.3728	1.9586	0.192	0	0	0.1162	0.8012	3.5836	8.6336	9.4298	19.2116	6.5028
70%ile	2.683	1.0472	0.1046	0	0	0	0.31	1.495	5.1348	5.1652	11.852	4.8286
60%ile	2.2786	0.7646	0.0746	0	0	0	0.117	0.593	2.578	3.7004	8.6844	4.007
50%ile	1.786	0.521	0.053	0	0	0	0.029	0.388	1.214	2.533	6.107	3.255
40%ile	1.5044	0.4394	0.0366	0	0	0	0	0.151	0.7078	1.821	4.3002	2.6678
30%ile	1.1952	0.3604	0.0244	0	0	0	0	0.0586	0.3022	1.4138	2.6404	2.21
20%ile	0.935	0.2876	0.0024	0	0	0	0	0	0.2274	0.9148	1.6672	1.7758
10%ile	0.5814	0.1934	0	0	0	0	0	0	0.0758	0.4978	0.737	1.2982
1%ile	0.32588	0.06452	0	0	0	0	0	0	0	0.10384	0.35336	0.42724

Removing AIPs from the Klein catchment would require concerted effort by both government and non-government stakeholder, including the following agencies/stakeholder:

- Department of Water and Sanitation (DWS)
- Breede Overberg Catchment Management Agency
- Cape Nature
- Overstrand Municipality
- Private landowners

An audit of all water use in the Klein catchment should be undertaken by BOCMA as a priority first step in order to identify and all legal and illegal uses of water in the catchment, to quantify their level of use. Thereafter, steps need to be taken to eliminate all illegal abstractions and to ensure legal users do not exceed their allowable limits.

In respect of non-flow related impacts, priority interventions that need to be undertaken by the respective authorities, landowners and other stakeholders are listed in Table 6.3.

Table 6.3. Priority non-flow related interventions that need to be implemented by the respective authorities, landowners and other stakeholders to improve the health status of the Klein estuary to a "B" class.

Measure	Responsibility
9. Reduce levels of inorganic nutrients in inflowing water from the catchment	
• Reduction in fertilizer use in the catchment	Landowners, farmers
• Educate landowners/farmers on impacts of excessive fertilizer use on the Klein estuary	BOCMA, Cape Nature, Overstrand municipality
• Improve quality of effluent from Standford WWTW	Overstrand municipality
10. Reduce direct inputs of inorganic nutrient into the estuary	
• Eliminate septic and conservancy tanks from properties on the banks of the Klein estuary through provision of sewage reticulation infrastructure	Overstrand municipality
11. Implement a mouth management plan that satisfies ecological requirements of the estuary (increased breaching water level, improved nursery function, improved water quality, increase connectivity with the Botvlei Estuary through aligning open periods where possible)	Overstrand municipality, Department of Environmental Affairs & Development Planning
12. Institute and enforce appropriate development set-back line around the estuary that provide adequate protection for estuarine fauna and flora	Overstrand municipality, Department of Environmental Affairs & Development Planning
13. Management of recreational activities on the estuary through zonation to reduce impacts of kite boarding and sailing on bird populations	Overstrand municipality, Cape Nature
14. Improved compliance in respect of use of living marine and estuarine resources (legal and illegal fishing)	Department of Agriculture Forestry & Fisheries (DAFF), Overstrand municipality
15. Establish a statutory protected area that covers at least 50% of the estuary in accordance with recommendations tabled by Turpie *et al.* 2004, Turpie & Clark 2007, Turpie *et al*. 2012)	Department of Environmental Affairs (DEA), Cape Nature, Overstrand municipality
16. Motivate for Ramsar status to increase national and international awareness of this important estuary. The systems meats all the criteria for being declared a Ramsar site	Department of Environmental Affairs (DEA), Cape Nature

6.2 Resource quality objectives

Note that since the Klein estuary has to be restored from a C to a B-category, the thresholds of potential concern (TPCs) should be seen as targets to be met within 5 years. Thereafter the estuary should be maintained such that these thresholds are not breached. The TPCs for the Klein estuary area listed in Table 6.4 and Table 6.5.

Table 6.4. Ecological specifications and thresholds of potential concern for abiotic components

Abiotic Component	Ecological Specification	Threshold of Potential Concern
Water quality	Salinity structure and the occurrence of different abiotic states should correspond as closely as possible with the Reference condition; State 5 (Closed hypersaline) should not occur at all.	• % time in State 1 (Open, marine) drops below 10% • Salinity in any part of the estuary exceed 35
	Water quality of the influent water at the head of the estuary and in the estuary itself should approximate Reference conditions as closely as possible. Important risk factors include elevated pH and nutrient levels in the influent waters and low oxygen levels in the estuary especially at night.	• pH levels in influent waters at the head of the estuary rise above 7.5 • Dissolved Inorganic Nitrogen (DIN) levels in influent waters at the head of the estuary exceed 1000 µg/ℓ • Dissolved Inorganic Nitrogen (DIN) levels in influent waters at the head of the estuary exceed 30 µg/ℓ • Dissolved oxygen levels in the estuary drop below 4 mg/ ℓ • Levels of contaminants (herbicides, pesticides, trace metals and hydrocarbons) in influent water at the head of the estuary or in the estuary itself exceed SA Water Quality Guideline levels
Hydrodynamics	Estuary should be allowed to function as naturally as possible within minimal human intervention	• Mouth is breached artificially when water level is <2.6 m • Amount of time mouth remains open drops below 22%, averaged over a period of 3 years
Sediment dynamics	Flood and breaching regimes to maintain the sediment distribution patterns and aquatic habitat (instream physical habitat) so as not to exceed TPCs for biota	• As for hydrodynamics above

Table 6.5. Ecological specifications and thresholds of potential concern for biotic components

Component	Ecological Specification	Threshold of Potential Concern
Microalgae	Phytoplankton biomass, measured as water column chlorophyll-a should not exceed 10 µg l^{-1}. Maintain high subtidal benthic microalgae biomass during the closed mouth phase and high intertidal benthic microalgae biomass during the open phase.	Phytoplankton biomass greater than 10 µg l^{-1}. Deviation in benthic microalgae biomass by 20 % compared with Present State concentrations. No brackish epipelic diatoms are found during the closed phase
Macrophytes	Maintain the distribution of plant community types i.e. Submerged macrophyte, *Ruppia cirrhosa* beds during closed mouth brackish conditions, salt marsh, *Salicornia meyeriana* marsh during open mouth conditions, *Phragmites australis* stands in the middle / upper reaches and salt marsh grasses indicative of brackish conditions.	Greater than 20% change in the area covered by different macrophyte habitats for baseline open and closed mouth conditions.
Benthic Invertebrates	The estuary should have viable populations of *Callianassa kraussi* in sandy zones and *U. Africana* in muddy zones. Breeding in both species ceases at salinities lower than 17 ppt during prolonged mouth phase. In *U. africana* and export of larvae into marine and postlarvae back to estuary ceases.	Abundance of *C. kraussi* and *U. Africana* drops below 50% of recorded total abundances in each season. No recruits in population recorded. (Identify zones where these are abundant based from the study and these would be where the above would be assessed)
Zooplankton	Prolonged close mouth would result in a loss of marine species (e.g. *Pseudodiaptomus sp.)* from the zooplankton community,	Absence of indicator marine species (*Pseudodiaptomus sp.)* changes by more than 50% of current levels (still to be determined).
Fish	Retain the following fish assemblages in the estuary (based on abundance): estuarine species (20-30%), estuarine associated marine species (60-70%) and indigenous freshwater species (<1%). All numerically dominant species are represented by 0+ juveniles.	Level of estuary associated marine species drops below 50% of total abundance. Level of estuarine species increases above 50% of total abundance. Occurrence of alien freshwater species in the estuary. Absence of 0+ juveniles of any of the dominant fish species.
Birds	The estuary should contain a rich avifaunal community that includes representatives of all the original groups, significant numbers of migratory waders and terns, as well as a healthy breeding population of resident waders. The estuary should support thousands of birds in summer and hundreds in winter.	Numbers of waterfowl drop below 600, waders below 100 in summer, and terns below 250 Overall numbers of bird species drop below 1000 for 3 consecutive counts.

6.3 Monitoring requirements

Recommended minimum monitoring requirements to ascertain impacts of changes in freshwater flow to the estuary and any improvement or reductions therein are listed in Table 6.6.

Table 6.6. Recommended minimum requirements for long term monitoring

Ecological Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. stations)
Hydrodynamics	Record water levels	Continuous	DWA station G4R004 (Yacht Club Jetty)
	Measure freshwater inflow into the estuary	Continuous	At the head of the estuary
	Aerial photographs of estuary (spring low tide)	Every 3 years	Entire estuary
Sediment dynamics	Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detailed in the mouth (every 100m). The vertical accuracy should be about 5 cm.	Every 3 years	Entire estuary
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)	Every 3 years (with invert sampling)	Entire estuary
Water quality	Collect data on conductivity, temperature, suspended matter/turbidity, dissolved oxygen, pH, inorganic nutrients and organic content in river inflow	Monthly continuous	At river inflow
	Assess and better quantify wastewater input (e.g. nutrients and organics) from point and diffuse sources (e.g. caravan park, WWTW).	Once-off detailed Possibly long-term (e.g. peak seasons) if input remains significant (preferably these should be mitigated)	In stream (source/s)
	Record longitudinal salinity and temperature profiles (and any other in situ measurements possible e.g. pH, DO, turbidity)	Seasonally, every year	Entire estuary (12 stations)
	Take water quality measurements along the length of the estuary (surface and bottom samples) for system variable (pH, dissolved oxygen, suspended solids/turbidity) and inorganic nutrients in addition to the longitudinal salinity and temperature profiles	Seasonal surveys, every 3 years or when significant change in water inflows or quality expected	Entire estuary (12 stations)

Ecological Component	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. stations)
Microalgae	Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. HPLC or fluoroprobe Intertidal and subtidal benthic chlorophyll-a measurements	Summer and winter survey every 3 years	Entire estuary (5 stations)
Macrophytes	Ground-truthed maps; Record number of plant community types, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit; Record percentage plant cover, salinity, water level, sediment moisture content and turbidity on a series of permanent transects along an elevation gradient; Take measurements of depth to water table and ground water salinity in supratidal marsh areas	Summer survey every 3 years	Entire estuary (5 stations)
Benthic Invertebrates	Record species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary. Record benthic invertebrate species and abundance, based on van Veen type grab samples in subtidal and core samples in intertidal at a series of stations up the estuary, and prawn holes density. Measures of sediment characteristics at each station	Summer and winter survey every 3 years	Entire estuary (6 stations)
Zooplankton	Record species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary.	Summer and winter every 3 years	Entire estuary 6 stn
Fish	Record species and abundance of fish, based on seine net and gill net sampling.	Summer and winter survey every 3 years	Entire estuary (6 stations)
Birds	Undertake counts of all water associated birds, identified to species level.	A series of monthly counts, followed by winter and summer survey every year	Entire estuary (4 sections)

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8 APPENDIX A. Data available for the study

Component	Baseline information requirements for high confidence	Data available for this study
General	Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the present state, as well as the Reference condition (if available).	1938, 1980, 2014
	Available orthophotographs	1938, 1980, 2014
Hydrology	Catchment size delineation	WR2005
	Measured river inflow data (gauging stations) at the head of the estuary over a 5-15 year period	G4H006
	Measured rainfall data in the catchment (or in a representative adjacent catchment)	
	Hydrological parameters (evaporation rates, radiation rates)	
	Flow losses (e.g. abstraction, impoundment) and gains (e.g. discharges, transfer schemes)	
	Flood hydrographs	
Bathymetry	Bathymetric/topographical surveys including berm height, cross sections at 10 – 50 m in the mouth region, cross section profiles at 500 m to 1000 m intervals upstream of the mouth, and floodplain topography.	De Decker (1989), CSIR (1992), CSIR (1994)
Hydrodynamics	Continuous water level recordings near mouth of the estuary	G4R004: 1979-2014
	Water level recordings at 2-6 stations along the length of the estuary over a spring and a neap tidal cycle (i.e. at least a 14 day period)	
	Long term data on daily mouth state (open/closed/overtopping) for temporarily open/ closed estuaries, particularly in systems that have a semi-closed mouth state.	1980-2014
	Data on wave conditions.	Yes
Sediments	Sediment grabs samples collected using a Van Veen or a Zabalocki-type Eckman grab (to characterize recent sediment movement) for particle size analyses, along entire estuary at 500 to 1 000 m intervals.	Scott *et al.* (1952), De Decker (1989), this study (2015)
	Sediment core samples collected using a corer (for historical sediment characterization) at intervals similar to cross-section profiles (see bathymetry) or where considered appropriate by sediment specialist; collected at 3 - 6 year intervals, as well as after flood events.	
	Sediment load at head of estuary (including detritus component – particulate carbon/loss on ignition).	
Water quality	Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary and in near-shore seawater	DWS Station: G6H4 – 1980-2015; In the estuary: 1999-2015
	Longitudinal salinity and temperature profiles (*in situ*) collected over a spring and neap tide during high and low tide at: end of low flow season (i.e. period of maximum seawater intrusion) peak of high flow season (i.e. period of maximum flushing by river water)	1999-2015
	Water quality measurements, i.e. system variables (pH, DO, turbidity, suspended solids, TDS and temperature) and nutrients (inorganic nitrogen [nitrite, nitrate and ammonia], reactive	1999-2015

Component	Baseline information requirements for high confidence	Data available for this study
	phosphate and silicate) taken along the length of the estuary (surface and bottom samples) on a spring and a neap high tide: end of low flow season peak of high flow season	
	Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary	
	Effluent discharges at end of pipe just before entering the estuary - measurements of flow rate and other parameters, depending on the composition of the effluent	1980-2012, Overstrand Municiaplity
Microalgae	Data on relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae, during typical high and low flow conditions	Scott *et al*. (1952), De Decker (1989)
	Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions,.	
	Intertidal and subtidal benthic chlorophyll-a measurements,	
	Along with measures of water salinity, inorganic nutrients, sediment particle size and total organic matter.	
Macroalgae	Ground-truthed aerial photographs or maps	De Decker's (1989), Turpie and Clark (2007)
	Data on number of plant community types, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit	
	Permanent transects along an elevation gradient with measurements of percentage plant cover, salinity, water level, sediment moisture content and turbidity	
	Measurements of depth to water table and ground water salinity in supratidal marsh areas	
Invertebrates	Species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary.	Scott *et al*. (1952), De Decker (1989)
	Benthic invertebrate species and abundance, based on subtidal grab samples and intertidal core samples at a series of stations up the estuary, and pump sampling or counts of hole densities.	
	Organic matter and particle size analysis of sediment at each station	
Fish	Species and abundance data of fish, based on seine net and gill net sampling at about 2km intervals along the estuary, including all habitat types, e.g. *Zostera* beds, prawn beds, sand flats, and with at least one sample sets in the 0 to 1 ppt reach of the system. These data should be available for four seasons of the year, or for low and high flow periods in a series of years.	Scott *et al*. (1952), De Decker (1989), recent data: 2000-2014
Birds	One year of monthly counts of all water associated birds, by species, for the whole estuary, preferably separated into counting areas and/or a series of at least 10 years of summer and winter counts, in addition to historical data on the same.	Single count from 1981, annual CWAC counts from 2001-2012 some anecdotal historic information, and some monthly counts undertaken in recent years

9 APPENDIX B

Natural flows into Estuary (at Stanford)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	1.18	0.75	0.43	0.24	0.20	0.14	0.64	0.33	62.18	15.69	28.09	6.51
1921	3.08	1.09	0.48	1.04	0.42	0.76	0.34	0.33	13.08	1.73	6.13	2.64
1922	1.71	21.88	2.11	0.31	0.12	0.08	4.01	10.66	5.95	9.87	8.40	4.73
1923	2.87	15.59	1.71	0.36	0.19	0.14	0.14	0.17	15.75	1.72	9.58	3.86
1924	2.39	2.83	1.06	0.25	0.13	0.10	0.18	0.20	53.27	5.68	7.43	4.26
1925	3.63	1.82	0.61	0.20	0.10	0.07	0.06	0.44	0.74	23.65	4.23	3.12
1926	20.74	5.61	0.74	0.24	0.15	0.13	0.14	1.69	1.40	1.06	7.96	2.17
1927	1.35	0.97	0.48	0.24	0.11	0.12	0.11	0.08	2.45	0.62	1.60	2.67
1928	1.32	1.14	0.48	0.15	0.05	0.10	0.24	0.33	0.68	11.22	3.16	2.31
1929	1.47	0.82	0.52	0.29	0.25	0.50	0.35	0.56	0.53	0.66	5.75	6.63
1930	2.48	1.39	0.52	0.20	0.11	0.09	6.43	1.06	0.71	8.97	14.08	4.62
1931	10.86	2.82	0.65	0.29	0.37	0.19	0.10	0.98	2.17	2.14	1.73	30.51
1932	4.69	1.21	0.47	0.19	0.10	0.08	0.09	0.75	11.12	4.78	22.76	4.77
1933	2.01	0.93	0.32	0.13	0.09	0.06	0.05	0.19	0.39	3.30	9.18	9.58
1934	4.31	1.97	0.55	0.17	0.09	0.07	1.12	5.19	2.63	3.15	2.60	2.64
1935	2.11	1.56	0.54	0.80	0.26	0.14	0.14	1.34	0.96	1.73	1.82	2.40
1936	1.75	1.72	0.95	0.33	0.11	0.13	0.15	0.15	8.18	20.95	4.01	5.62
1937	3.23	1.28	0.58	0.29	0.14	0.68	0.89	2.46	1.54	2.12	3.45	23.21
1938	5.69	1.89	0.63	0.24	0.97	0.44	0.56	0.85	0.72	3.42	7.96	3.16
1939	1.96	1.08	0.45	0.18	16.59	3.82	3.71	1.06	5.81	2.65	2.23	2.23
1940	1.72	2.65	0.71	0.22	0.12	0.07	11.12	11.39	10.67	9.63	13.98	30.53
1941	5.28	1.72	0.69	0.31	0.16	0.10	0.13	6.63	8.53	2.58	2.74	2.76
1942	2.10	0.89	1.15	10.77	0.98	1.03	0.84	1.71	1.28	2.33	3.87	3.86
1943	2.85	1.99	0.72	0.25	0.12	0.08	0.08	9.18	22.11	3.40	24.20	56.47
1944	5.56	1.29	0.50	0.21	0.10	0.07	0.63	56.59	18.42	45.67	52.85	7.98
1945	11.68	3.70	0.72	0.26	0.14	2.54	0.47	0.41	1.02	1.40	1.44	5.08
1946	2.27	0.90	0.29	0.12	0.06	0.81	0.27	0.56	0.78	16.14	3.17	2.29
1947	2.24	1.20	0.43	0.16	0.09	1.30	0.56	0.40	1.05	3.25	1.67	2.01
1948	36.62	6.66	0.62	0.27	0.13	0.08	2.44	1.29	1.01	1.43	3.58	2.64
1949	1.90	3.55	0.83	0.24	0.11	0.06	1.26	0.37	0.38	6.20	1.60	2.92
1950	2.39	5.19	1.09	1.83	0.39	0.17	3.26	1.14	32.46	24.73	23.94	49.51
1951	7.61	1.54	0.53	0.20	0.12	0.10	0.14	0.80	1.06	4.03	9.99	14.02
1952	5.32	14.63	1.92	0.37	0.17	0.10	3.31	1.16	1.54	4.73	2.74	2.21
1953	1.62	2.51	0.59	0.19	0.11	0.12	0.56	28.36	6.60	52.76	62.70	7.79
1954	2.49	1.19	0.49	0.21	27.46	1.96	0.37	0.41	2.33	12.40	48.17	7.19
1955	4.45	2.14	0.63	0.22	0.13	0.17	0.17	15.44	9.90	4.53	14.56	5.23
1956	3.49	1.55	1.32	0.47	0.28	0.30	0.35	24.21	41.23	32.05	56.25	11.07
1957	31.79	4.78	0.56	0.19	0.14	1.25	0.76	22.25	3.39	2.22	21.29	5.13
1958	2.49	1.29	0.45	0.22	0.15	0.17	21.60	9.78	2.40	2.37	20.82	5.55
1959	5.32	2.13	0.55	0.26	0.14	0.11	0.14	1.28	6.00	2.49	2.17	1.96
1960	1.44	0.65	0.52	1.21	0.39	0.11	0.12	0.67	1.30	1.71	6.32	5.63
1961	2.81	1.29	0.41	0.32	0.17	0.77	1.16	0.64	15.79	3.10	54.17	5.67
1962	14.42	3.93	0.81	0.30	0.14	0.11	0.15	0.72	0.86	7.95	12.68	3.14

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1963	1.78	1.03	0.59	0.24	0.12	0.54	0.28	0.40	15.28	4.30	21.44	5.40
1964	3.00	7.66	2.08	0.30	0.20	0.67	0.56	1.73	1.08	1.70	1.79	1.55
1965	1.52	0.86	0.44	0.20	0.09	0.09	0.49	0.45	0.45	2.66	13.71	4.24
1966	2.41	0.97	0.34	0.14	0.07	0.07	18.13	2.20	7.25	3.71	9.46	4.27
1967	2.55	1.36	0.52	0.20	0.13	0.10	0.11	1.47	7.16	2.31	5.11	2.72
1968	2.04	1.18	0.44	0.21	0.15	0.12	1.31	0.46	1.19	0.93	1.16	1.15
1969	1.26	0.70	0.22	0.08	0.49	0.11	0.05	0.33	2.51	4.49	11.66	3.89
1970	2.76	1.18	0.41	0.17	0.09	0.09	0.14	0.45	1.42	4.56	14.77	3.36
1971	2.48	1.25	0.61	0.29	0.19	0.16	3.05	1.70	1.93	2.04	9.55	4.01
1972	2.60	1.06	0.40	0.16	0.08	0.05	0.05	0.34	0.34	1.40	1.23	1.61
1973	1.13	0.59	0.26	0.10	0.06	0.05	0.05	4.34	1.00	0.87	59.49	8.25
1974	5.14	2.08	0.57	0.24	0.11	0.08	0.09	4.23	0.93	4.90	9.74	3.18
1975	2.80	1.33	0.41	0.13	0.08	0.19	1.48	1.29	40.65	9.40	13.16	5.21
1976	3.94	3.74	1.16	0.40	1.82	0.47	0.48	4.81	4.61	27.72	24.60	5.76
1977	2.75	1.25	1.61	0.52	0.18	0.16	0.33	0.29	0.35	5.07	8.18	2.98
1978	2.39	1.17	0.48	0.25	9.14	1.54	0.21	3.30	2.25	3.28	4.12	2.84
1979	4.68	1.91	0.47	0.24	0.15	0.09	0.09	0.64	5.22	1.36	1.36	1.29
1980	1.13	3.86	1.12	3.91	1.17	1.28	4.23	1.49	1.04	11.00	12.33	8.97
1981	3.62	1.39	0.55	0.23	0.11	0.08	14.33	2.03	2.05	1.40	1.84	1.73
1982	1.16	0.56	0.21	0.10	1.29	0.42	0.17	18.13	8.94	10.82	6.82	8.66
1983	3.60	1.32	0.49	0.19	0.11	0.11	0.20	13.60	2.10	1.96	1.90	3.10
1984	4.70	1.75	1.82	1.39	0.53	0.59	1.53	0.74	0.85	35.68	5.53	3.60
1985	3.35	1.57	0.55	0.20	0.19	0.80	0.40	0.32	1.13	1.60	61.56	7.98
1986	3.20	1.76	0.64	0.22	0.12	0.09	2.00	1.55	2.93	1.98	9.95	6.71
1987	3.23	1.05	0.39	0.16	0.09	0.06	1.44	0.82	2.09	1.44	7.39	3.12
1988	2.40	1.22	0.42	0.19	0.11	9.52	20.62	2.61	12.87	34.56	34.98	17.74
1989	6.33	2.34	0.68	0.24	0.39	0.17	8.57	5.22	16.07	9.21	5.16	3.73
1990	2.07	1.10	0.49	0.24	0.13	0.09	0.09	0.70	2.40	28.72	3.53	2.95
1991	9.43	3.04	0.57	0.22	0.13	0.11	0.78	2.11	4.82	2.80	5.34	7.84
1992	8.32	3.04	0.65	0.25	0.38	0.18	63.40	2.48	6.81	50.23	19.59	5.29
1993	2.01	0.87	0.45	0.22	0.13	0.11	0.79	1.35	41.64	5.85	5.02	3.62
1994	2.18	1.03	2.25	0.57	0.17	1.51	0.75	7.05	2.32	4.71	15.82	4.48
1995	2.67	1.53	3.93	0.64	0.28	0.21	0.18	0.20	1.97	6.69	2.84	3.49
1996	15.64	5.10	1.31	0.45	0.18	0.10	0.58	14.91	4.45	2.51	3.07	2.67
1997	1.73	3.72	0.67	0.25	0.12	0.10	1.90	31.06	3.18	3.13	5.41	3.47
1998	1.68	5.10	28.45	0.85	0.30	0.15	0.98	0.56	0.59	0.71	2.54	12.27
1999	2.65	0.96	0.38	0.27	0.14	1.10	0.38	0.34	0.49	5.42	2.09	3.44
2000	2.02	0.89	0.35	0.16	0.09	0.05	0.16	0.64	0.46	18.21	7.97	4.62
2001	3.41	1.46	0.48	4.00	0.95	0.20	0.37	2.59	3.50	8.68	12.68	5.85
2002	3.25	1.40	0.54	0.23	0.14	34.20	1.12	2.81	1.33	1.27	43.11	7.08
2003	3.36	1.38	0.52	0.28	0.16	0.12	0.64	0.30	0.84	3.26	1.78	1.57
2004	21.99	2.50	0.63	1.38	0.34	0.13	68.24	8.03	13.01	4.03	4.31	3.53

Natural flows out of estuary (at the mouth)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	1.29	0.82	0.49	0.27	0.25	0.17	0.66	0.35	66.33	17.1	28.29	6.88
1921	3.26	1.15	0.54	1.38	0.55	0.89	0.4	0.36	13.27	1.84	6.26	2.73
1922	1.78	22.99	2.5	0.35	0.14	0.09	4.99	11.82	6.55	10.29	8.73	5.14
1923	3.23	15.88	1.82	0.4	0.23	0.17	0.17	0.2	16.1	1.91	10.76	4.4
1924	2.56	3.6	1.35	0.29	0.16	0.12	0.2	0.22	54.18	6.06	7.68	4.41
1925	3.81	1.92	0.64	0.22	0.11	0.08	0.07	0.51	0.86	25.07	4.86	3.31
1926	24.68	6.98	0.81	0.28	0.18	0.16	0.16	1.87	1.49	1.11	8.18	2.3
1927	1.41	1.04	0.54	0.26	0.12	0.13	0.12	0.08	2.57	0.68	1.7	2.87
1928	1.42	1.25	0.53	0.16	0.06	0.13	0.28	0.38	0.73	11.94	3.5	2.43
1929	1.55	0.9	0.57	0.31	0.3	0.62	0.43	0.72	0.63	0.76	6.05	7.07
1930	2.72	1.54	0.58	0.22	0.13	0.1	7.05	1.32	0.77	9.22	14.45	4.86
1931	11.41	3.06	0.69	0.32	0.45	0.22	0.12	1.19	2.41	2.32	1.87	33.06
1932	5.65	1.31	0.52	0.22	0.12	0.09	0.1	0.81	11.7	5.12	23.09	4.98
1933	2.13	1	0.35	0.15	0.1	0.07	0.06	0.2	0.41	3.48	10.12	10.23
1934	4.62	2.09	0.58	0.19	0.11	0.08	1.25	5.55	3.14	3.39	2.73	2.79
1935	2.22	1.62	0.58	0.9	0.3	0.16	0.15	1.54	1.1	1.93	1.99	2.55
1936	1.87	1.84	1.07	0.37	0.12	0.16	0.18	0.17	8.76	22.97	4.75	5.97
1937	3.46	1.39	0.64	0.32	0.17	0.96	1.11	2.69	1.72	2.36	3.76	24.33
1938	6.42	2.12	0.7	0.27	1.05	0.55	0.66	0.92	0.77	3.77	8.9	3.58
1939	2.1	1.15	0.5	0.2	21.58	5.49	4.1	1.24	6.37	2.99	2.4	2.48
1940	1.88	3	0.84	0.25	0.14	0.08	12.86	12.22	10.85	9.98	14.25	31.25
1941	5.67	1.87	0.76	0.35	0.19	0.12	0.15	7.25	9.44	2.92	2.91	2.95
1942	2.24	0.96	1.27	11.46	1.23	1.09	0.92	1.81	1.38	2.6	4.27	4.2
1943	3.03	2.2	0.8	0.28	0.14	0.1	0.09	9.62	23.56	3.93	25.07	58.16
1944	6.22	1.43	0.57	0.24	0.13	0.09	0.69	59.39	20.65	47.15	57.59	9.59
1945	13.23	4.31	0.8	0.3	0.17	2.79	0.56	0.47	1.2	1.55	1.58	5.71
1946	2.6	1	0.32	0.14	0.08	0.89	0.32	0.62	0.84	17.21	3.65	2.44
1947	2.36	1.27	0.46	0.18	0.1	1.64	0.74	0.46	1.27	3.55	1.84	2.2
1948	43.95	9.11	0.69	0.31	0.16	0.1	2.63	1.58	1.15	1.59	4.05	2.94
1949	2.05	3.86	0.95	0.27	0.13	0.08	1.41	0.44	0.42	6.62	1.81	3.19
1950	2.57	5.47	1.23	2	0.46	0.19	3.64	1.38	34.25	25.66	24.32	53.75
1951	9.13	1.68	0.6	0.24	0.15	0.12	0.16	0.92	1.21	4.3	11.86	16.82
1952	6.22	14.93	2.04	0.41	0.2	0.12	3.7	1.39	1.84	5.31	3.07	2.38
1953	1.75	2.65	0.64	0.21	0.13	0.14	0.71	31.26	7.91	55.83	67.31	9.17
1954	2.77	1.31	0.56	0.25	29.68	2.72	0.42	0.46	2.52	12.73	50.92	8.23
1955	4.94	2.37	0.7	0.26	0.16	0.22	0.21	16.88	11.39	5.41	15.94	5.81
1956	3.76	1.68	1.64	0.58	0.32	0.35	0.41	26.51	43.92	34.21	60.14	12.89
1957	34.26	5.64	0.63	0.23	0.18	1.36	0.85	23.57	3.96	2.35	22.22	5.57
1958	2.63	1.38	0.5	0.25	0.17	0.21	24.51	11.29	2.69	2.56	21.59	5.97
1959	5.77	2.33	0.61	0.3	0.17	0.13	0.16	1.39	6.38	2.74	2.3	2.07
1960	1.52	0.69	0.64	1.56	0.51	0.13	0.14	0.82	1.69	2.07	6.67	6
1961	3.04	1.39	0.45	0.4	0.2	0.92	1.38	0.72	16.67	3.53	54.85	6.04
1962	15.4	4.35	0.87	0.33	0.17	0.13	0.19	0.74	0.9	8.48	13.18	3.35

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1963	1.9	1.1	0.67	0.27	0.14	0.61	0.33	0.44	16.89	5.02	21.93	5.78
1964	3.22	9.51	2.74	0.35	0.23	0.8	0.65	1.93	1.21	1.87	1.96	1.67
1965	1.61	0.91	0.47	0.22	0.1	0.1	0.66	0.57	0.51	3.45	15.12	4.87
1966	2.62	1.07	0.38	0.17	0.09	0.08	19.88	2.84	8.44	4.32	9.75	4.5
1967	2.72	1.47	0.58	0.23	0.16	0.12	0.13	1.57	7.56	2.6	5.51	2.96
1968	2.21	1.28	0.48	0.23	0.17	0.14	1.5	0.55	1.31	1.03	1.25	1.23
1969	1.4	0.77	0.24	0.08	0.51	0.11	0.05	0.36	2.78	4.93	12.1	4.17
1970	2.96	1.28	0.46	0.19	0.11	0.1	0.17	0.51	1.64	5.1	15.28	3.64
1971	2.63	1.33	0.67	0.32	0.21	0.18	3.19	1.9	2.1	2.18	9.95	4.34
1972	2.76	1.13	0.43	0.18	0.09	0.06	0.06	0.46	0.41	1.56	1.34	1.74
1973	1.22	0.65	0.29	0.11	0.06	0.06	0.05	4.77	1.19	0.94	61.22	8.98
1974	5.35	2.19	0.6	0.26	0.13	0.09	0.11	4.5	1.06	5.25	10.13	3.38
1975	3.07	1.47	0.45	0.15	0.09	0.2	2.01	1.53	44.08	10.79	13.45	5.45
1976	4.15	4.01	1.26	0.44	2.05	0.56	0.53	5.4	5.23	28.69	25.4	6.12
1977	2.94	1.36	1.98	0.65	0.22	0.2	0.38	0.33	0.39	6.72	9.11	3.39
1978	2.63	1.28	0.55	0.28	10.89	2.13	0.25	3.61	2.54	3.56	4.35	3.01
1979	5.53	2.27	0.53	0.27	0.17	0.1	0.11	0.76	5.54	1.51	1.45	1.37
1980	1.23	4.7	1.42	4.7	1.46	1.35	5.05	1.81	1.12	11.49	12.76	9.28
1981	3.8	1.48	0.6	0.26	0.13	0.1	16.41	2.75	2.31	1.56	2.04	1.94
1982	1.3	0.63	0.24	0.12	1.6	0.56	0.2	18.71	10.07	11.62	7.86	9.16
1983	3.8	1.45	0.55	0.23	0.14	0.13	0.24	14.88	2.59	2.14	2.05	3.32
1984	4.97	1.87	1.9	1.63	0.64	0.62	1.78	0.85	0.96	37.35	6.24	3.77
1985	3.59	1.7	0.6	0.23	0.21	0.91	0.45	0.35	1.21	1.78	67.45	10.12
1986	3.41	1.99	0.73	0.26	0.15	0.11	2.21	1.79	3.11	2.13	10.46	7.09
1987	3.4	1.12	0.43	0.18	0.1	0.08	2.02	1.07	2.31	1.6	7.81	3.4
1988	2.57	1.31	0.46	0.21	0.13	10.24	22.15	3.13	13.72	35.61	37.94	20.09
1989	7.16	2.53	0.75	0.28	0.45	0.2	9.01	5.86	16.86	9.87	5.51	3.97
1990	2.24	1.2	0.54	0.27	0.15	0.11	0.11	0.88	2.71	30	4.05	3.2
1991	10.67	3.54	0.63	0.25	0.16	0.13	0.88	2.36	5.53	3.15	5.72	8.27
1992	9.51	3.52	0.73	0.29	0.46	0.22	64.46	2.97	7.09	53.87	21.76	5.8
1993	2.18	0.96	0.52	0.26	0.16	0.13	0.91	1.46	45.37	7.27	5.27	3.83
1994	2.36	1.12	2.66	0.71	0.2	2.19	1.05	7.4	2.59	5.17	16.2	4.73
1995	2.88	1.67	4.25	0.75	0.31	0.24	0.2	0.22	2.17	7.47	3.24	3.93
1996	16.54	5.51	1.41	0.49	0.21	0.12	0.64	15.53	4.95	2.71	3.37	2.86
1997	1.91	3.85	0.71	0.27	0.14	0.12	2.46	32.9	3.85	3.46	5.68	3.68
1998	1.82	6.21	29.02	0.93	0.34	0.18	1.18	0.68	0.65	0.77	3.26	13.56
1999	3.13	1.04	0.42	0.31	0.16	1.35	0.48	0.42	0.57	5.65	2.31	3.72
2000	2.18	0.96	0.38	0.18	0.1	0.06	0.19	0.71	0.5	19.02	8.88	5.08
2001	3.67	1.6	0.54	4.9	1.27	0.23	0.44	2.74	4.2	9.42	14.05	6.54
2002	3.49	1.52	0.59	0.27	0.17	34.89	1.38	3.07	1.47	1.37	44.87	7.88
2003	3.55	1.47	0.57	0.31	0.18	0.14	0.67	0.32	0.96	3.64	1.99	1.68
2004	23.48	3.06	0.68	1.54	0.4	0.15	77.61	11.32	13.92	4.47	4.62	3.78

Present Day Flow into Estuary (at Stanford)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.37	0.123	0	0	0	0	0.02	0	55.287	13.751	25.974	5.369
1921	1.931	0.316	0.01	0.319	0.02	0.113	0	0	9.941	0.878	5.132	1.631
1922	0.74	19.605	0.951	0	0	0	2.112	7.961	4.907	8.333	7.029	3.58
1923	1.756	13.881	0.627	0	0	0	0	0	12.194	0.824	8.076	2.734
1924	1.34	1.621	0.376	0	0	0	0	0	47.642	4.711	6.13	3.259
1925	2.599	0.732	0.042	0	0	0	0	0	0.112	19.152	3.203	2.15
1926	17.8	3.962	0.11	0	0	0	0	0.495	0.383	0.251	5.713	1.18
1927	0.415	0.194	0.005	0	0	0	0	0	1.003	0.064	0.476	1.177
1928	0.396	0.261	0.006	0	0	0	0	0	0.062	7.606	1.895	1.216
1929	0.489	0.138	0.014	0	0	0.029	0	0.084	0.048	0.087	3.17	4.868
1930	1.254	0.436	0.021	0	0	0	3.522	0.298	0.092	7.184	12.195	3.529
1931	9.275	1.499	0.071	0	0	0	0	0.222	0.811	0.822	0.62	27.08
1932	3.302	0.358	0.003	0	0	0	0	0.068	7.574	3.56	20.478	3.681
1933	0.929	0.212	0	0	0	0	0	0	0	1.569	6.082	7.769
1934	3.215	0.819	0.023	0	0	0	0.223	2.775	1.4	2.067	1.528	1.685
1935	1.038	0.56	0.017	0.112	0	0	0	0.332	0.2	0.573	0.655	1.156
1936	0.696	0.675	0.19	0	0	0	0	0	5.109	18.056	2.862	4.504
1937	2.08	0.387	0.042	0	0	0.176	0.204	0.996	0.526	0.915	2.144	20.335
1938	4.409	0.815	0.071	0	0.15	0.017	0.053	0.12	0.09	1.617	5.963	2.036
1939	0.914	0.261	0	0	12.426	2.744	2.348	0.317	4.705	1.747	1.274	1.296
1940	0.662	1.506	0.114	0	0	0	7.582	9.786	9.419	8.144	12.525	28.203
1941	4.07	0.681	0.092	0	0	0	0	3.66	6.787	1.611	1.886	1.804
1942	1.014	0.162	0.244	8.548	0.315	0.173	0.132	0.684	0.406	1.394	2.935	2.819
1943	1.738	0.882	0.098	0	0	0	0	6.05	19.688	2.366	21.849	52.791
1944	4.204	0.43	0.027	0	0	0	0.034	50.228	16.362	42.383	48.563	6.348
1945	9.987	2.329	0.105	0	0	1.031	0.021	0	0.235	0.407	0.459	3.471
1946	1.127	0.178	0	0	0	0.093	0	0.03	0.104	12.108	2.135	1.336
1947	1.263	0.33	0	0	0	0.381	0.09	0	0.267	1.543	0.628	0.806
1948	31.667	4.729	0.061	0	0	0	0.981	0.369	0.234	0.434	1.967	1.542
1949	0.821	2.266	0.152	0	0	0	0.276	0	0	3.63	0.567	1.774
1950	1.301	3.777	0.266	0.589	0	0	1.487	0.394	29.494	22.341	22.013	45.448
1951	5.978	0.575	0.036	0	0	0	0	0.124	0.241	2.045	7.378	11.44
1952	3.971	12.959	0.724	0	0	0	1.511	0.304	0.597	3.2	1.652	1.137
1953	0.594	1.423	0.04	0	0	0	0.073	23.582	5.359	48.583	58.022	6.27
1954	1.379	0.357	0.02	0	23.289	1.177	0	0	1.014	11.034	44.245	5.804
1955	3.311	0.945	0.068	0	0	0	0	11.321	8.479	3.43	12.394	3.996
1956	2.446	0.563	0.473	0.026	0	0	0	19.881	37.888	29.279	52.057	9.275
1957	28.845	3.214	0.053	0	0	0.259	0.104	18.675	2.433	1.26	19.182	3.946
1958	1.479	0.414	0	0	0	0	16.864	8.321	1.469	1.53	18.579	4.392
1959	4.169	0.914	0.036	0	0	0	0	0.284	3.319	1.387	1.117	0.94
1960	0.467	0.059	0.047	0.364	0.01	0	0	0.101	0.431	0.743	3.994	4.2
1961	1.633	0.39	0	0	0	0.123	0.281	0.074	12.331	2.172	50.507	4.513
1962	12.641	2.649	0.147	0	0	0	0	0.046	0.123	5.18	10.636	2.059
1963	0.738	0.261	0.06	0	0	0.009	0	0	11.323	3.278	19.184	4.295
1964	1.92	5.933	1.119	0	0	0.084	0.045	0.537	0.263	0.566	0.67	0.524

1965	0.484	0.143	0	0	0	0	0.062	0.023	0.003	1.114	10.209	2.93
1966	1.237	0.208	0	0	0	0	13.593	1.264	6.033	2.71	7.956	3.196
1967	1.513	0.443	0.021	0	0	0	0	0.374	4.445	1.17	3.782	1.666
1968	1.029	0.319	0	0	0	0	0.315	0.017	0.265	0.191	0.299	0.306
1969	0.351	0.094	0	0	0	0	0	0	1.021	2.312	8.765	2.494
1970	1.53	0.337	0	0	0	0	0	0	0.393	2.335	11.676	2.322
1971	1.421	0.374	0.055	0	0	0	1.399	0.54	0.787	1.055	7.704	2.975
1972	1.474	0.262	0	0	0	0	0	0	0	0.371	0.322	0.526
1973	0.29	0.049	0	0	0	0	0	2.18	0.251	0.16	52.307	6.765
1974	4.031	0.92	0.034	0	0	0	0	2.142	0.196	3.208	7.894	2.158
1975	1.738	0.42	0	0	0	0	0.546	0.346	35.392	7.766	11.54	4.165
1976	2.883	2.567	0.317	0	0.572	0.017	0.003	2.867	3.346	25.081	22.534	4.649
1977	1.614	0.39	0.628	0.053	0	0	0	0	0	3.052	5.702	1.837
1978	1.274	0.315	0.01	0	6.242	0.86	0	1.808	1.302	2.284	3.145	1.85
1979	3.436	0.83	0	0	0	0	0	0.072	2.808	0.423	0.414	0.392
1980	0.293	2.287	0.42	2.301	0.41	0.292	2.796	0.616	0.248	9.301	10.564	7.597
1981	2.462	0.486	0.035	0	0	0	10.188	1.198	1.082	0.552	1.008	0.755
1982	0.317	0.043	0	0	0.365	0.027	0	14.088	7.657	9.176	5.527	7.193
1983	2.417	0.449	0.018	0	0	0	0	9.52	1.09	1.142	1.017	2.188
1984	3.612	0.674	0.609	0.384	0.048	0.011	0.441	0.121	0.15	32.258	4.327	2.543
1985	2.311	0.536	0.026	0	0	0.112	0	0	0.229	0.504	54.853	6.316
1986	2.101	0.725	0.08	0	0	0	0.686	0.459	1.342	0.856	8.061	5.416
1987	2.06	0.275	0	0	0	0	0.56	0.202	0.839	0.495	5.017	1.957
1988	1.276	0.339	0	0	0	6.282	18.333	1.628	11.377	31.807	31.916	15.501
1989	5.033	1.127	0.092	0	0	0	5.694	3.965	14.369	7.706	4.092	2.674
1990	0.983	0.304	0.011	0	0	0	0	0.125	0.944	24.607	2.439	1.998
1991	7.907	1.679	0.04	0	0	0	0.099	0.761	2.752	1.729	3.974	6.337
1992	6.793	1.688	0.081	0	0	0	57.749	1.55	5.833	46.029	17.355	4.087
1993	0.902	0.185	0.006	0	0	0	0.116	0.337	36.216	4.521	3.953	2.562
1994	1.126	0.246	0.933	0.075	0	0.832	0.316	4.586	1.359	3.591	13.778	3.367
1995	1.651	0.556	2.383	0.088	0	0	0	0	0.68	4.452	1.746	2.466
1996	13.685	3.834	0.41	0	0	0	0.015	11.476	3.514	1.602	2.161	1.6
1997	0.714	2.595	0.062	0	0	0	0.68	26.828	2.194	2.243	4.303	2.387
1998	0.634	3.564	25.91	0.158	0	0	0.217	0.06	0.051	0.089	1.248	9.71
1999	1.452	0.201	0	0	0	0.27	0	0	0.021	2.968	1.008	2.227
2000	0.897	0.16	0	0	0	0	0	0.048	0	13.836	6.613	3.545
2001	2.321	0.493	0.005	2.194	0.38	0	0	1.1	2.175	7.036	10.685	4.642
2002	2.135	0.475	0.029	0	0	29.69	0.411	1.799	0.511	0.461	40.089	5.74
2003	2.265	0.46	0.02	0	0	0	0.022	0	0.143	1.506	0.651	0.532
2004	18.899	1.3	0.054	0.348	0	0	60.32	6.096	11.589	2.968	3.345	2.469

Present Day Flow out of the Estuary (at the mouth)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0	0	0	0	0	0	0	0	54.297	14.625	26.297	5.761
1921	1.296	0	0	0	0	0	0	0	6.39	0.817	5.325	1.312
1922	0.284	20.34	0	0	0	0	0	8.159	5.738	8.935	7.344	3.629
1923	1.65	13.55	0	0	0	0	0	0	7.877	1.005	9.658	3.062
1924	1.021	1.963	0	0	0	0	0	0	43.84	5.07	6.524	2.875
1925	2.428	0	0	0	0	0	0	0	0	15.778	3.813	2.08
1926	21.752	4.18	0	0	0	0	0	0	0	0	2.581	0.9
1927	0	0	0	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	0	0	0	0	0.983	2.119	0.934
1929	0	0	0	0	0	0	0	0	0	0	0	4.771
1930	0.94	0	0	0	0	0	0	0	0	7.202	12.745	3.541
1931	9.656	0.609	0	0	0	0	0	0	0	0	0	29.02
1932	3.563	0	0	0	0	0	0	0	2.869	4.005	20.966	3.497
1933	0.476	0	0	0	0	0	0	0	0	0	2.971	8.428
1934	3.132	0	0	0	0	0	0	0	0	2.216	1.4	1.691
1935	0.521	0	0	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	1.145	20.533	3.383	4.833
1937	1.771	0	0	0	0	0	0	0	0	0	2.011	21.627
1938	4.808	0.093	0	0	0	0	0	0	0	0	5.908	2.084
1939	0.419	0	0	0	13.727	3.398	2.675	0.347	5.627	2.107	1.173	1.477
1940	0.217	1.287	0	0	0	0	4.816	10.689	9.642	8.731	12.754	29.048
1941	3.949	0	0	0	0	0	0	0	7.34	1.807	2.047	1.845
1942	0.54	0	0	7.03	0	0	0	0	0	1.666	3.521	3.054
1943	1.301	0.423	0	0	0	0	0	1.747	21.607	2.702	23.072	54.499
1944	4.263	0	0	0	0	0	0	47.855	18.92	44.067	53.157	7.293
1945	11.494	1.909	0	0	0	0	0	0	0	0	0	2.932
1946	0.946	0	0	0	0	0	0	0	0	8.328	2.535	1.189
1947	0.818	0	0	0	0	0	0	0	0	0	0	0
1948	38.886	5.726	0	0	0	0	0	0	0	0	1.227	1.612
1949	0.437	1.987	0	0	0	0	0	0	0	0	0.411	2.038
1950	0.972	3.472	0	0	0	0	0	0	31.278	23.403	22.408	49.572
1951	6.626	0	0	0	0	0	0	0	0	0	7.442	14.141
1952	4.211	12.646	0	0	0	0	0	0	0	3.186	1.874	0.94
1953	0.123	0.843	0	0	0	0	0	22.631	6.812	51.928	62.381	7.128
1954	1.109	0	0	0	21.874	0.856	0	0	0.848	11.604	47.443	6.423
1955	3.581	0.23	0	0	0	0	0	8.69	10.346	4.566	13.717	4.118
1956	2.353	0	0	0	0	0	0	18.572	40.952	31.452	55.786	10.841
1957	31.154	2.828	0	0	0	0	0	16.533	3.027	1.137	20.475	3.958
1958	1.129	0	0	0	0	0	14.866	9.954	1.556	1.812	19.671	4.526
1959	4.371	0.033	0	0	0	0	0	0	0	1.407	1.1	0.7
1960	0	0	0	0	0	0	0	0	0	0	2.64	4.508
1961	1.317	0	0	0	0	0	0	0	9.368	2.603	51.484	4.511
1962	13.536	2.09	0	0	0	0	0	0	0	1.346	11.326	1.809
1963	0.379	0	0	0	0	0	0	0	8.566	4.064	19.89	4.529

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1964	1.607	7.449	0.364	0	0	0	0	0	0	0	0.205	0.247
1965	0.038	0	0	0	0	0	0	0	0	0	9.22	3.378
1966	0.788	0	0	0	0	0	10.059	1.762	7.695	3.371	8.26	3.046
1967	1.196	0	0	0	0	0	0	0	0	1.599	4.386	1.519
1968	0.774	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	4.337	2.615
1970	1.263	0	0	0	0	0	0	0	0	0	10.779	2.341
1971	0.986	0	0	0	0	0	0	0	0	0	7.92	3.176
1972	0.949	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	47.568	7.253
1974	3.818	0	0	0	0	0	0	0	0	0.858	8.445	1.994
1975	1.706	0	0	0	0	0	0	0	35.504	9.143	11.813	4.139
1976	2.64	2.198	0	0	0	0	0	0	4.272	26.416	23.3	4.723
1977	1.164	0	0	0	0	0	0	0	0	1.368	6.761	2.178
1978	1.001	0	0	0	4.513	0.326	0	1.72	1.795	2.731	3.398	1.761
1979	4.187	0.083	0	0	0	0	0	0	0	0	0	0
1980	0	2.272	0	1.283	0	0	2.384	0.643	0.356	10.108	11.102	7.791
1981	1.932	0	0	0	0	0	7.43	1.548	1.593	0.592	1.304	0.82
1982	0	0	0	0	0	0	0	10.113	9.212	10.226	6.556	7.435
1983	1.883	0	0	0	0	0	0	5.86	1.456	1.461	0.996	2.335
1984	3.548	0	0	0	0	0	0	0	0	32.228	4.935	2.379
1985	2.219	0	0	0	0	0	0	0	0	0	57.06	8.052
1986	1.742	0.309	0	0	0	0	0	0	0	0	8.737	5.665
1987	1.554	0	0	0	0	0	0	0	0	0	3.723	2.018
1988	0.985	0	0	0	0	2.271	19.933	2.04	12.639	33.079	34.774	17.634
1989	5.475	0.29	0	0	0	0	1.944	4.861	15.519	8.601	4.307	2.565
1990	0.477	0	0	0	0	0	0	0	0	22.494	2.694	2.157
1991	9.086	1.138	0	0	0	0	0	0	0.814	2.076	4.526	6.731
1992	7.895	1.193	0	0	0	0	54.859	2.04	6.338	50.16	19.256	4.127
1993	0.346	0	0	0	0	0	0	0	35.949	5.873	4.175	2.456
1994	0.852	0	0	0	0	0	0	3.791	1.747	4.334	14.189	3.374
1995	1.409	0	1.09	0	0	0	0	0	0	2.986	2.151	2.94
1996	14.455	3.447	0	0	0	0	0	7.917	4.266	1.668	2.622	1.309
1997	0.514	1.948	0	0	0	0	0	26.032	2.806	2.77	4.535	2.222
1998	0.087	4.297	25.572	0	0	0	0	0	0	0	0	10.833
1999	1.208	0	0	0	0	0	0	0	0	0	0.333	2.463
2000	0.401	0	0	0	0	0	0	0	0	9.373	7.811	3.893
2001	2.15	0	0	0.439	0	0	0	0	2.395	8.063	12.217	5.17
2002	1.757	0	0	0	0	25.63	0.183	2.235	0.552	0.578	42.283	6.358
2003	1.838	0	0	0	0	0	0	0	0	0	0	0
2004	18.564	0.754	0	0	0	0	66.262	9.024	12.908	3.21	3.754	2.425

Scenario 1 Flow into Estuary (at Stanford)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.625	0.27	0.079	0	0	0	0.132	0.021	60.399	15.506	27.836	6.119
1921	2.444	0.499	0.101	0.58	0.131	0.263	0.047	0.025	11.403	1.328	5.894	2.099
1922	1.144	21.517	1.367	0.02	0	0	2.901	9.375	5.738	9.604	8.066	4.238
1923	2.307	15.172	0.937	0.042	0	0	0	0	13.872	1.332	9.397	3.384
1924	1.834	2.223	0.593	0	0	0	0	0	51.318	5.448	7.103	3.833
1925	3.152	1.137	0.162	0	0	0	0	0.067	0.232	21.675	3.911	2.679
1926	20.426	4.919	0.253	0	0	0	0	0.85	0.674	0.455	6.94	1.661
1927	0.738	0.389	0.095	0	0	0	0	0	1.375	0.181	0.808	2.001
1928	0.679	0.543	0.096	0	0	0	0	0.038	0.182	9.218	2.608	1.684
1929	0.838	0.289	0.105	0.002	0.009	0.128	0.065	0.194	0.156	0.244	4.393	5.934
1930	1.901	0.761	0.114	0	0	0	4.669	0.618	0.284	8.382	13.887	4.195
1931	10.486	2.029	0.201	0.012	0.07	0	0	0.362	1.26	1.395	1.215	30.079
1932	4.089	0.574	0.092	0	0	0	0	0.204	8.961	4.454	22.553	4.268
1933	1.376	0.38	0.023	0	0	0	0	0	0.028	1.975	7.746	9.139
1934	3.845	1.246	0.128	0	0	0	0.453	3.684	2.196	2.619	2.087	2.206
1935	1.492	0.953	0.117	0.241	0.004	0	0	0.606	0.365	0.989	1.276	1.86
1936	1.138	1.11	0.379	0.031	0	0	0	0	6.323	20.449	3.575	5.279
1937	2.633	0.629	0.148	0.012	0	0.313	0.431	1.523	0.882	1.566	2.904	22.823
1938	5.184	1.187	0.189	0	0.355	0.113	0.151	0.282	0.226	2.569	7.255	2.671
1939	1.378	0.466	0.076	0	15.034	3.435	2.989	0.607	5.564	2.298	1.762	1.803
1940	1.121	2.073	0.238	0	0	0	9.208	11.019	10.498	9.326	13.655	30.271
1941	4.735	1.036	0.224	0.022	0	0	0	4.859	7.933	2.157	2.401	2.32
1942	1.486	0.328	0.482	9.775	0.519	0.401	0.281	1.212	0.827	2.004	3.578	3.461
1943	2.262	1.369	0.226	0	0	0	0	7.102	21.913	2.995	24.041	56.309
1944	4.948	0.669	0.121	0	0	0	0.13	54.575	18.319	45.515	52.672	7.449
1945	11.342	2.992	0.24	0.008	0	1.427	0.116	0.068	0.497	0.787	0.969	4.472
1946	1.649	0.34	0.012	0	0	0.243	0.017	0.125	0.248	14.235	2.744	1.819
1947	1.733	0.554	0.059	0	0	0.569	0.245	0.079	0.571	2.136	1.139	1.508
1948	36.017	5.928	0.172	0.006	0	0	1.364	0.645	0.484	0.87	3.074	2.076
1949	1.28	2.869	0.302	0	0	0	0.547	0.066	0.051	4.753	1.082	2.394
1950	1.795	4.61	0.493	1.001	0.068	0	2.154	0.719	32.124	24.553	23.654	49.307
1951	7.042	0.858	0.133	0	0	0	0	0.249	0.435	2.568	9.377	13.536
1952	4.793	14.199	1.141	0.047	0	0	2.033	0.698	1.14	4.184	2.201	1.695
1953	1.041	1.932	0.146	0	0	0	0.181	26.546	6.372	52.7	62.553	7.302
1954	1.894	0.583	0.112	0	25.859	1.552	0.055	0.066	1.644	12.205	48.086	6.718
1955	3.99	1.428	0.183	0	0	0	0	13.256	9.735	4.211	14.283	4.728
1956	3.017	0.844	0.787	0.124	0.013	0.022	0.055	22.549	41.262	31.798	56.095	10.698
1957	31.492	3.983	0.161	0	0	0.54	0.227	20.934	3.079	1.734	21.176	4.618
1958	1.965	0.633	0.081	0	0	0	19.42	9.577	1.99	2.026	20.662	5.087
1959	4.889	1.371	0.138	0.003	0	0	0	0.569	4.539	1.999	1.605	1.4
1960	0.83	0.182	0.148	0.675	0.117	0	0	0.208	0.865	1.111	5.09	5.001
1961	2.241	0.625	0.056	0.05	0	0.236	0.491	0.21	14.273	2.767	54.132	5.179
1962	14.096	3.27	0.304	0.017	0	0	0	0.188	0.298	6.346	12.349	2.586
1963	1.179	0.441	0.167	0	0	0.097	0.018	0.05	13.413	4.018	21.242	4.958
1964	2.443	7.137	1.519	0.022	0	0.188	0.142	0.962	0.526	1.033	1.3	0.991
1965	0.965	0.304	0.068	0	0	0	0.173	0.121	0.09	1.904	11.968	3.797

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1966	1.76	0.385	0.036	0	0	0	15.705	1.814	7.064	3.383	9.167	3.798
1967	2.003	0.71	0.116	0	0	0	0	0.7	5.622	1.812	4.687	2.193
1968	1.506	0.542	0.067	0	0	0	0.58	0.109	0.517	0.359	0.552	0.536
1969	0.639	0.226	0	0	0.053	0	0	0.011	1.419	3.267	10.855	3.176
1970	2.1	0.551	0.062	0	0	0	0	0.07	0.671	3.092	14.031	2.876
1971	1.906	0.603	0.168	0.005	0	0	1.793	1.113	1.416	1.549	9.134	3.587
1972	1.97	0.456	0.052	0	0	0	0	0.082	0.057	0.66	0.558	0.836
1973	0.502	0.158	0	0	0	0	0	2.666	0.42	0.336	57.827	7.882
1974	4.697	1.339	0.145	0	0	0	0	2.598	0.407	4.275	9.391	2.693
1975	2.272	0.68	0.055	0	0	0	0.833	0.715	39.106	9.117	12.849	4.795
1976	3.451	3.165	0.524	0.053	0.94	0.11	0.091	3.917	4.143	27.609	24.316	5.326
1977	2.118	0.622	1.003	0.163	0	0	0.03	0.019	0.042	4.186	7.059	2.416
1978	1.832	0.539	0.099	0	7.675	1.169	0	2.48	1.823	2.94	3.8	2.367
1979	4.226	1.217	0.088	0	0	0	0	0.174	3.596	0.864	0.904	0.761
1980	0.587	3.248	0.649	3.042	0.641	0.582	3.659	1.001	0.607	10.563	12.072	8.604
1981	3.007	0.728	0.139	0	0	0	12.218	1.593	1.691	1.002	1.485	1.227
1982	0.585	0.144	0	0	0.567	0.17	0	16.097	8.773	10.572	6.439	8.297
1983	2.969	0.695	0.111	0	0	0	0	11.272	1.698	1.628	1.481	2.743
1984	4.272	1.02	1.175	0.732	0.15	0.11	0.841	0.29	0.46	35.257	5.183	3.089
1985	2.88	0.893	0.126	0	0	0.236	0.066	0.018	0.479	0.812	60.832	7.554
1986	2.637	1.103	0.191	0	0	0	1.058	0.805	2.177	1.483	9.388	6.332
1987	2.595	0.458	0.053	0	0	0	0.877	0.478	1.275	0.801	6.21	2.532
1988	1.844	0.566	0.06	0	0	7.531	20.245	2.219	12.736	34.371	34.736	17.4
1989	5.882	1.618	0.224	0	0.056	0	6.767	4.861	15.952	8.893	4.756	3.228
1990	1.453	0.495	0.103	0	0	0	0	0.239	1.382	27.43	3.074	2.531
1991	9.069	2.28	0.14	0	0	0	0.225	1.141	3.93	2.285	4.773	7.471
1992	7.915	2.293	0.202	0.003	0.078	0	61.798	2.129	6.62	50.146	19.263	4.785
1993	1.346	0.349	0.094	0	0	0	0.237	0.628	40.219	5.508	4.645	3.127
1994	1.608	0.432	1.416	0.205	0	1.246	0.517	5.552	1.875	4.364	15.578	3.966
1995	2.161	0.879	3.186	0.196	0.008	0	0	0	1.047	5.72	2.368	3.111
1996	15.317	4.545	0.642	0.072	0	0	0.106	13.165	4.216	2.107	2.724	2.11
1997	1.178	3.171	0.186	0	0	0	1.115	29.593	2.851	2.817	5.074	2.947
1998	1.032	4.444	27.948	0.315	0.019	0	0.356	0.167	0.175	0.235	1.927	11.427
1999	2.037	0.377	0.047	0.013	0	0.436	0.09	0.06	0.126	3.987	1.605	2.863
2000	1.364	0.331	0.029	0	0	0	0	0.148	0.085	15.916	7.733	4.217
2001	2.886	0.779	0.095	2.934	0.592	0	0.056	1.602	3.061	8.179	12.388	5.432
2002	2.671	0.729	0.127	0	0	32.294	0.654	2.355	0.918	0.867	43.146	6.664
2003	2.814	0.699	0.117	0.007	0	0	0.134	0.01	0.278	1.973	1.182	1.04
2004	21.303	1.801	0.174	0.638	0.049	0	66.913	7.657	12.886	3.586	3.991	3.035

Scenario 1 Flow out of the Estuary (at the mouth)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.171	0	0	0	0	0	0	0	60.742	16.619	28.192	6.575
1921	1.839	0	0	0	0	0	0	0	8.695	1.285	6.109	1.796
1922	0.699	22.438	0.445	0	0	0	0.984	11.026	6.671	10.278	8.437	4.357
1923	2.262	14.891	0	0	0	0	0	0	9.685	1.545	11.178	3.804
1924	1.543	2.696	0	0	0	0	0	0	47.691	5.871	7.539	3.474
1925	3.01	0.372	0	0	0	0	0	0	0	19.561	4.63	2.642
1926	25.048	5.371	0	0	0	0	0	0	0	0	4.769	1.402
1927	0.155	0	0	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	0	0	0	0	5.587	2.889	1.421
1929	0.28	0	0	0	0	0	0	0	0	0	1.904	6.469
1930	1.627	0.177	0	0	0	0	0.966	0.787	0.266	8.913	14.5	4.247
1931	10.96	1.18	0	0	0	0	0	0	0	0	1.097	33.353
1932	4.512	0	0	0	0	0	0	0	4.613	4.957	23.096	4.119
1933	0.943	0	0	0	0	0	0	0	0	0	5.301	9.909
1934	3.814	0.377	0	0	0	0	0	0	3.106	2.807	1.981	2.238
1935	0.994	0.183	0	0	0	0	0	0	0	0	0.37	1.835
1936	0.753	0.495	0	0	0	0	0	0	2.954	23.269	4.222	5.668
1937	2.363	0	0	0	0	0	0	0	0	1.678	3.379	24.305
1938	5.707	0.503	0	0	0	0	0	0	0	0.452	8.698	2.789
1939	0.906	0	0	0	17.271	4.373	3.382	0.667	6.58	2.715	1.69	2.026
1940	0.703	1.912	0	0	0	0	6.75	12.062	10.752	9.972	13.929	31.237
1941	4.682	0.378	0	0	0	0	0	1.267	9.377	2.411	2.591	2.394
1942	1.035	0	0	8.635	0	0	0	0.176	0.991	2.542	4.233	3.752
1943	1.857	0.946	0	0	0	0	0	2.89	24.078	3.421	25.412	58.304
1944	5.119	0	0	0	0	0	0	52.904	21.257	47.45	58.071	8.668
1945	13.111	2.675	0	0	0	0	0	0	0	0	0.571	5.346
1946	1.525	0	0	0	0	0	0	0	0	11.109	3.226	1.697
1947	1.307	0	0	0	0	0	0	0	0	0	1.099	1.607
1948	44.587	7.342	0	0	0	0	0	0	0	0	3.869	2.196
1949	0.923	2.642	0	0	0	0	0	0	0	1.53	1.069	2.703
1950	1.496	4.353	0	0	0	0	0	0.943	34.725	25.774	24.113	54.152
1951	7.948	0.146	0	0	0	0	0	0	0	0	11.474	16.713
1952	5.185	13.939	0.093	0	0	0	0	0.104	1.751	5.169	2.478	1.529
1953	0.592	1.375	0	0	0	0	0	26.231	8.048	56.569	67.697	8.394
1954	1.669	0	0	0	24.932	1.359	0	0	1.584	12.832	51.751	7.515
1955	4.345	0.752	0	0	0	0	0	10.897	11.857	5.499	15.841	4.948
1956	2.97	0	0	0	0	0	0	22.192	44.781	34.338	60.484	12.574
1957	34.223	3.745	0	0	0	0	0	19.468	3.769	1.634	22.627	4.705
1958	1.64	0	0	0	0	0	18.021	11.466	2.125	2.34	21.886	5.293
1959	5.167	0.525	0	0	0	0	0	0	1.311	2.356	1.611	1.178
1960	0.286	0	0	0	0	0	0	0	0	0.37	5.643	5.372
1961	1.965	0	0	0	0	0	0	0	12.124	3.27	55.224	5.24
1962	15.159	2.782	0	0	0	0	0	0	0	2.969	13.124	2.372
1963	0.839	0	0	0	0	0	0	0	11.241	4.927	22.032	5.257

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1964	2.168	8.968	0.877	0	0	0	0	0	0	0.866	1.48	0.735
1965	0.534	0	0	0	0	0	0	0	0	0	12.576	4.353
1966	1.347	0	0	0	0	0	12.524	2.422	8.929	4.147	9.52	3.685
1967	1.714	0	0	0	0	0	0	0	1.922	2.289	5.36	2.087
1968	1.281	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	9.959	3.345
1970	1.866	0	0	0	0	0	0	0	0	0	14.548	2.943
1971	1.497	0	0	0	0	0	0	0	0.218	1.712	9.826	3.843
1972	1.473	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	55.821	8.494
1974	4.52	0.411	0	0	0	0	0	0	0	3.7	10.009	2.564
1975	2.286	0	0	0	0	0	0	0	40.657	10.73	13.173	4.811
1976	3.244	2.841	0	0	0	0	0	2.156	5.17	29.108	25.216	5.461
1977	1.701	0	0	0	0	0	0	0	0	3.042	8.276	2.827
1978	1.598	0	0	0	6.349	0.737	0	2.444	2.366	3.433	4.091	2.308
1979	5.121	0.53	0	0	0	0	0	0	0	0.699	0.967	0.541
1980	0.253	3.828	0	2.158	0	0	3.69	1.083	0.729	11.452	12.682	8.851
1981	2.506	0	0	0	0	0	9.94	2.065	2.246	1.068	1.816	1.327
1982	0.138	0	0	0	0	0	0	13.141	10.521	11.759	7.645	8.625
1983	2.469	0.099	0	0	0	0	0	8.517	2.147	1.978	1.485	2.926
1984	4.254	0.1	0.312	0.169	0	0	0	0	0.27	37.704	5.911	2.956
1985	2.83	0.169	0	0	0	0	0	0	0	0	65.681	9.653
1986	2.314	0.728	0	0	0	0	0	0	0.509	1.714	10.258	6.646
1987	2.119	0	0	0	0	0	0	0	0	0	6.597	2.642
1988	1.583	0	0	0	0	3.717	22.106	2.72	14.141	35.82	38.097	19.934
1989	6.465	0.814	0	0	0	0	3.17	5.867	17.237	9.9	5.029	3.159
1990	0.975	0	0	0	0	0	0	0	0	26.284	3.418	2.732
1991	10.458	1.823	0	0	0	0	0	0	2.693	2.692	5.39	7.94
1992	9.219	1.881	0	0	0	0	59.197	2.703	7.172	54.896	21.534	4.911
1993	0.818	0	0	0	0	0	0	0	41.151	7.102	4.91	3.056
1994	1.364	0	0.106	0	0	0	0	5.887	2.307	5.186	16.052	4.015
1995	1.954	0.199	2.777	0	0	0	0	0	0	4.812	2.84	3.659
1996	16.239	4.228	0	0	0	0	0	9.899	5.053	2.206	3.237	1.851
1997	1.009	2.546	0	0	0	0	0	29.652	3.577	3.4	5.353	2.817
1998	0.509	5.366	27.705	0	0	0	0	0	0	0	1.068	13.124
1999	1.875	0	0	0	0	0	0	0	0	0.708	1.904	3.147
2000	0.896	0	0	0	0	0	0	0	0	11.842	9.086	4.643
2001	2.759	0.06	0	2.137	0	0	0	0	3.999	9.331	14.155	6.078
2002	2.333	0	0	0	0	28.469	0.471	2.835	0.982	1.001	45.638	7.419
2003	2.42	0	0	0	0	0	0	0	0	0	0	0.225
2004	23.034	1.348	0	0	0	0	74.828	11.146	14.36	3.902	4.453	3.032

Scenario 2 Flow into Estuary (at Stanford)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.41	0.145	0.009	0	0	0	0.029	0	59.671	15.174	27.504	5.787
1921	2.112	0.34	0.026	0.453	0.051	0.148	0	0	10.773	0.982	5.562	1.767
1922	0.834	21.163	1.102	0	0	0	2.538	8.929	5.39	9.272	7.734	3.906
1923	1.976	14.84	0.668	0	0	0	0	0	13.165	0.933	8.989	3.052
1924	1.502	1.912	0.483	0	0	0	0	0	50.655	5.117	6.772	3.501
1925	2.82	0.835	0.053	0	0	0	0	0	0.143	20.889	3.579	2.347
1926	20.095	4.587	0.131	0	0	0	0	0.583	0.415	0.273	6.304	1.306
1927	0.444	0.219	0.021	0	0	0	0	0	1.107	0.082	0.54	1.348
1928	0.432	0.298	0.021	0	0	0	0	0	0.077	8.519	2.102	1.347
1929	0.537	0.162	0.03	0	0	0.058	0	0.124	0.075	0.114	3.654	5.36
1930	1.506	0.502	0.037	0	0	0	4.048	0.484	0.113	7.875	13.555	3.863
1931	10.154	1.697	0.086	0	0	0	0	0.276	0.923	0.922	0.764	29.672
1932	3.757	0.393	0.018	0	0	0	0	0.086	8.331	4.002	22.221	3.937
1933	1.044	0.236	0	0	0	0	0	0	0	1.708	6.98	8.723
1934	3.513	0.93	0.036	0	0	0	0.262	3.218	1.734	2.297	1.69	1.858
1935	1.16	0.655	0.028	0.139	0	0	0	0.386	0.238	0.634	0.719	1.447
1936	0.815	0.788	0.224	0	0	0	0	0	5.68	19.95	3.243	4.947
1937	2.302	0.424	0.059	0	0	0.243	0.259	1.194	0.626	1.05	2.559	22.407
1938	4.852	0.909	0.09	0	0.177	0.043	0.081	0.142	0.107	1.815	6.889	2.298
1939	1.046	0.288	0.003	0	14.602	3.341	2.667	0.388	5.176	1.966	1.43	1.471
1940	0.789	1.741	0.147	0	0	0	8.668	10.65	10.166	8.994	13.323	29.939
1941	4.404	0.749	0.112	0	0	0	0	4.314	7.545	1.825	2.069	1.988
1942	1.154	0.185	0.28	9.397	0.407	0.195	0.157	0.836	0.485	1.628	3.246	3.129
1943	1.93	1.04	0.121	0	0	0	0	6.66	21.353	2.663	23.709	55.977
1944	4.616	0.481	0.046	0	0	0	0.051	53.942	17.987	45.183	52.34	7.117
1945	11.01	2.661	0.128	0	0	1.16	0.046	0	0.281	0.468	0.547	4.112
1946	1.327	0.206	0	0	0	0.116	0	0.048	0.123	13.39	2.412	1.487
1947	1.401	0.358	0	0	0	0.465	0.133	0	0.346	1.845	0.704	0.998
1948	35.592	5.618	0.08	0	0	0	1.096	0.442	0.275	0.547	2.615	1.753
1949	0.957	2.547	0.184	0	0	0	0.32	0	0	4.095	0.717	2.072
1950	1.473	4.146	0.31	0.709	0	0	1.732	0.508	31.744	24.221	23.322	48.975
1951	6.71	0.634	0.054	0	0	0	0	0.157	0.282	2.223	8.748	13.12
1952	4.461	13.867	0.834	0	0	0	1.688	0.412	0.759	3.862	1.873	1.293
1953	0.709	1.6	0.057	0	0	0	0.111	25.944	6.041	52.369	62.221	6.97
1954	1.562	0.399	0.038	0	25.418	1.449	0	0	1.214	11.845	47.754	6.386
1955	3.659	1.105	0.088	0	0	0	0	12.602	9.404	3.88	13.951	4.396
1956	2.685	0.607	0.593	0.054	0	0	0	21.857	40.93	31.466	55.763	10.366
1957	31.161	3.651	0.073	0	0	0.295	0.131	20.341	2.747	1.402	20.844	4.286
1958	1.633	0.447	0.007	0	0	0	18.832	9.245	1.658	1.694	20.33	4.755
1959	4.557	1.049	0.053	0	0	0	0	0.319	4.036	1.57	1.283	1.067
1960	0.528	0.073	0.078	0.518	0.04	0	0	0.139	0.631	0.886	4.52	4.678
1961	1.83	0.424	0	0	0	0.163	0.336	0.098	13.584	2.435	53.8	4.847
1962	13.764	2.939	0.168	0	0	0	0	0.056	0.139	5.758	11.88	2.254
1963	0.847	0.286	0.081	0	0	0.026	0	0	12.695	3.686	20.91	4.626

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1964	2.111	6.805	1.36	0	0	0.117	0.069	0.619	0.301	0.694	0.809	0.669
1965	0.648	0.162	0	0	0	0	0.103	0.051	0.021	1.461	11.398	3.309
1966	1.406	0.238	0	0	0	0	15.081	1.504	6.733	3.051	8.835	3.466
1967	1.671	0.48	0.037	0	0	0	0	0.433	4.97	1.364	4.281	1.861
1968	1.175	0.352	0	0	0	0	0.37	0.039	0.303	0.219	0.329	0.334
1969	0.392	0.114	0	0	0	0	0	0	1.151	2.533	10.049	2.83
1970	1.756	0.37	0	0	0	0	0	0	0.453	2.594	13.257	2.545
1971	1.574	0.405	0.073	0	0	0	1.526	0.608	1.047	1.18	8.642	3.255
1972	1.638	0.288	0	0	0	0	0	0.013	0	0.419	0.358	0.569
1973	0.32	0.065	0	0	0	0	0	2.398	0.302	0.182	56.249	7.55
1974	4.365	1.034	0.046	0	0	0	0	2.33	0.233	3.658	8.825	2.361
1975	1.94	0.464	0	0	0	0	0.674	0.494	38.532	8.785	12.517	4.464
1976	3.12	2.833	0.351	0	0.672	0.04	0.017	3.401	3.756	27.277	23.984	4.994
1977	1.786	0.428	0.764	0.086	0	0	0	0	0	3.722	6.49	2.093
1978	1.457	0.35	0.028	0	7.22	1.075	0	2.095	1.501	2.534	3.468	2.035
1979	3.894	0.967	0.016	0	0	0	0	0.103	3.035	0.473	0.57	0.445
1980	0.327	2.828	0.533	2.719	0.518	0.321	3.248	0.74	0.284	10.061	11.74	8.272
1981	2.675	0.521	0.05	0	0	0	11.554	1.459	1.261	0.661	1.153	0.895
1982	0.373	0.062	0	0	0.444	0.062	0	15.378	8.441	10.24	6.107	7.965
1983	2.637	0.507	0.035	0	0	0	0	10.691	1.317	1.289	1.149	2.411
1984	3.94	0.719	0.877	0.457	0.075	0.021	0.519	0.165	0.205	34.727	4.851	2.757
1985	2.548	0.589	0.041	0	0	0.142	0	0	0.256	0.558	60.02	7.222
1986	2.305	0.824	0.105	0	0	0	0.79	0.527	1.623	1.163	8.982	6.001
1987	2.263	0.303	0	0	0	0	0.701	0.371	0.983	0.563	5.64	2.187
1988	1.441	0.371	0	0	0	7.045	19.876	1.887	12.404	34.039	34.404	17.068
1989	5.55	1.286	0.112	0	0	0	6.276	4.492	15.62	8.561	4.424	2.896
1990	1.121	0.335	0.026	0	0	0	0	0.169	1.076	26.656	2.742	2.199
1991	8.737	1.958	0.058	0	0	0	0.126	0.874	3.326	1.963	4.451	7.055
1992	7.583	1.961	0.103	0	0.008	0	61.273	1.798	6.288	49.814	18.932	4.453
1993	1.014	0.213	0.024	0	0	0	0.148	0.374	39.482	5.176	4.313	2.795
1994	1.276	0.277	1.124	0.112	0	1.079	0.423	5.106	1.552	3.967	15.246	3.634
1995	1.829	0.609	2.863	0.118	0	0	0	0	0.78	5.122	1.992	2.757
1996	14.985	4.213	0.445	0	0	0	0.032	12.534	3.884	1.775	2.392	1.778
1997	0.846	2.839	0.077	0	0	0	0.846	29.1	2.52	2.485	4.742	2.615
1998	0.71	4.121	27.616	0.185	0	0	0.27	0.09	0.068	0.108	1.576	10.813
1999	1.705	0.229	0	0	0	0.333	0.02	0	0.042	3.33	1.247	2.541
2000	1.042	0.182	0	0	0	0	0	0.069	0.011	15.087	7.401	3.885
2001	2.554	0.546	0.021	2.629	0.498	0	0	1.212	2.665	7.782	12.056	5.1
2002	2.339	0.515	0.045	0	0	31.743	0.508	2.024	0.586	0.535	42.814	6.333
2003	2.482	0.494	0.034	0	0	0	0.032	0	0.176	1.677	0.715	0.573
2004	20.79	1.511	0.068	0.396	0	0	66.272	7.325	12.554	3.254	3.66	2.703

Scenario 2 Flow out of the Estuary (at the mouth)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0	0	0	0	0	0	0	0	59.478	16.287	27.86	6.243
1921	1.507	0	0	0	0	0	0	0	7.595	0.939	5.778	1.465
1922	0.39	22.084	0.18	0	0	0	0.622	10.579	6.324	9.946	8.105	4.025
1923	1.93	14.559	0	0	0	0	0	0	8.936	1.145	10.769	3.473
1924	1.211	2.385	0	0	0	0	0	0	47.028	5.54	7.207	3.142
1925	2.679	0.069	0	0	0	0	0	0	0	18.623	4.298	2.31
1926	24.716	5.039	0	0	0	0	0	0	0	0	3.424	1.048
1927	0	0	0	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	0	0	0	0	2.713	2.384	1.084
1929	0	0	0	0	0	0	0	0	0	0	0.269	5.896
1930	1.232	0	0	0	0	0	0	0.362	0.096	8.406	14.168	3.915
1931	10.628	0.849	0	0	0	0	0	0	0	0	0	32.614
1932	4.181	0	0	0	0	0	0	0	3.792	4.505	22.765	3.787
1933	0.611	0	0	0	0	0	0	0	0	0	4.22	9.493
1934	3.482	0.061	0	0	0	0	0	0	2.201	2.485	1.584	1.89
1935	0.662	0	0	0	0	0	0	0	0	0	0	0
1936	0.085	0.172	0	0	0	0	0	0	2.28	22.77	3.89	5.336
1937	2.032	0	0	0	0	0	0	0	0	0.236	3.033	23.888
1938	5.375	0.225	0	0	0	0	0	0	0	0	7.452	2.417
1939	0.574	0	0	0	16.764	4.279	3.06	0.448	6.192	2.384	1.358	1.694
1940	0.371	1.58	0	0	0	0	6.211	11.692	10.421	9.64	13.597	30.905
1941	4.35	0.092	0	0	0	0	0	0.699	8.989	2.079	2.259	2.063
1942	0.703	0	0	8.055	0	0	0	0	0.118	2.165	3.901	3.421
1943	1.525	0.616	0	0	0	0	0	2.45	23.518	3.089	25.08	57.972
1944	4.787	0	0	0	0	0	0	52.117	20.925	47.119	57.74	8.336
1945	12.779	2.344	0	0	0	0	0	0	0	0	0	4.189
1946	1.202	0	0	0	0	0	0	0	0	9.908	2.894	1.365
1947	0.975	0	0	0	0	0	0	0	0	0	0	0.857
1948	44.162	7.032	0	0	0	0	0	0	0	0	2.446	1.874
1949	0.6	2.32	0	0	0	0	0	0	0	0.53	0.704	2.381
1950	1.174	3.889	0	0	0	0	0	0.115	34.346	25.442	23.781	53.821
1951	7.617	0	0	0	0	0	0	0	0	0	9.523	16.297
1952	4.854	13.607	0	0	0	0	0	0	0	4.563	2.151	1.127
1953	0.26	1.044	0	0	0	0	0	25.559	7.717	56.237	67.365	8.062
1954	1.337	0	0	0	24.417	1.256	0	0	1.088	12.471	51.419	7.184
1955	4.013	0.43	0	0	0	0	0	10.244	11.525	5.167	15.509	4.617
1956	2.638	0	0	0	0	0	0	21.186	44.45	34.006	60.152	12.242
1957	33.891	3.413	0	0	0	0	0	18.534	3.437	1.302	22.295	4.374
1958	1.308	0	0	0	0	0	17.359	11.135	1.793	2.008	21.554	4.962
1959	4.835	0.203	0	0	0	0	0	0	0.555	1.928	1.288	0.845
1960	0	0	0	0	0	0	0	0	0	0	4.101	5.05
1961	1.554	0	0	0	0	0	0	0	10.989	2.938	54.892	4.908
1962	14.827	2.451	0	0	0	0	0	0	0	2.072	12.655	2.04
1963	0.507	0	0	0	0	0	0	0	10.298	4.595	21.7	4.925

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1964	1.836	8.636	0.717	0	0	0	0	0	0	0	0.805	0.413
1965	0.218	0	0	0	0	0	0	0	0	0	11.285	3.865
1966	0.993	0	0	0	0	0	11.865	2.111	8.597	3.815	9.188	3.353
1967	1.382	0	0	0	0	0	0	0	0.923	1.84	4.954	1.755
1968	0.949	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	6.609	2.999
1970	1.522	0	0	0	0	0	0	0	0	0	12.926	2.611
1971	1.165	0	0	0	0	0	0	0	0	0.32	9.334	3.512
1972	1.141	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	52.552	8.162
1974	4.188	0.106	0	0	0	0	0	0	0	2.643	9.442	2.232
1975	1.954	0	0	0	0	0	0	0	39.648	10.398	12.841	4.479
1976	2.912	2.509	0	0	0	0	0	1.176	4.783	28.776	24.884	5.129
1977	1.369	0	0	0	0	0	0	0	0	2.409	7.706	2.504
1978	1.224	0	0	0	5.824	0.643	0	2.06	2.043	3.028	3.759	1.976
1979	4.789	0.28	0	0	0	0	0	0	0	0	0.309	0.225
1980	0	2.955	0	1.835	0	0	3.018	0.822	0.406	10.95	12.35	8.519
1981	2.174	0	0	0	0	0	9.187	1.932	1.816	0.727	1.484	0.995
1982	0	0	0	0	0	0	0	11.74	10.189	11.428	7.313	8.293
1983	2.137	0	0	0	0	0	0	7.299	1.767	1.64	1.153	2.594
1984	3.922	0	0	0	0	0	0	0	0	35.692	5.579	2.624
1985	2.498	0	0	0	0	0	0	0	0	0	63.444	9.321
1986	1.982	0.448	0	0	0	0	0	0	0	0.803	9.851	6.314
1987	1.787	0	0	0	0	0	0	0	0	0	5.164	2.297
1988	1.18	0	0	0	0	3.171	21.737	2.388	13.809	35.488	37.765	19.602
1989	6.133	0.482	0	0	0	0	2.623	5.497	16.905	9.568	4.697	2.827
1990	0.643	0	0	0	0	0	0	0	0	25.057	3.086	2.4
1991	10.127	1.5	0	0	0	0	0	0	1.723	2.37	5.068	7.524
1992	8.887	1.549	0	0	0	0	58.6	2.371	6.84	54.564	21.202	4.579
1993	0.487	0	0	0	0	0	0	0	40.001	6.77	4.578	2.724
1994	1.032	0	0	0	0	0	0	4.959	1.985	4.789	15.721	3.683
1995	1.622	0	1.624	0	0	0	0	0	0	3.939	2.464	3.306
1996	15.908	3.896	0	0	0	0	0	9.123	4.721	1.874	2.905	1.52
1997	0.677	2.214	0	0	0	0	0	28.89	3.245	3.068	5.021	2.485
1998	0.187	5.043	27.373	0	0	0	0	0	0	0	0	12.511
1999	1.543	0	0	0	0	0	0	0	0	0	1.219	2.824
2000	0.573	0	0	0	0	0	0	0	0	10.833	8.755	4.311
2001	2.427	0	0	1.051	0	0	0	0	3.158	8.934	13.823	5.746
2002	2.002	0	0	0	0	27.836	0.325	2.503	0.65	0.669	45.306	7.087
2003	2.088	0	0	0	0	0	0	0	0	0	0	0
2004	21.213	1.058	0	0	0	0	73.896	10.814	14.028	3.571	4.121	2.701

Scenario 3 Flow into Estuary (at Stanford)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0	0	0	0	0	0	0	0	51.782	13.39	25.7	5.092
1921	1.477	0	0	0	0	0	0	0	7.33	0.544	4.844	1.262
1922	0.337	19.275	0.392	0	0	0	0	7.755	4.674	8.076	6.733	3.231
1923	1.374	13.475	0.075	0	0	0	0	0	9.272	0.525	7.888	2.418
1924	0.947	1.268	0	0	0	0	0	0	44.437	4.415	5.863	2.87
1925	2.234	0.272	0	0	0	0	0	0	0	15.556	2.915	1.813
1926	17.626	3.49	0	0	0	0	0	0	0	0	2.951	0.814
1927	0	0	0	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	0	0	0	0	2.309	1.58	0.851
1929	0.063	0	0	0	0	0	0	0	0	0	0	4.199
1930	0.852	0.001	0	0	0	0	0.878	0	0	6.683	11.937	3.201
1931	8.956	0.995	0	0	0	0	0	0	0	0	0	25.663
1932	2.895	0	0	0	0	0	0	0	4.044	3.286	20.215	3.32
1933	0.519	0	0	0	0	0	0	0	0	0	3.067	7.499
1934	2.845	0.334	0	0	0	0	0	0	1.186	1.752	1.179	1.369
1935	0.617	0.105	0	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	1.457	17.904	2.54	4.219
1937	1.68	0	0	0	0	0	0	0	0	0	1.321	20.112
1938	4.066	0.346	0	0	0	0	0	0	0	0	4.622	1.687
1939	0.493	0	0	0	10.827	2.289	2.043	0	4.471	1.457	0.924	0.998
1940	0.247	1.114	0	0	0	0	5.038	9.517	9.136	7.896	12.223	27.958
1941	3.679	0.231	0	0	0	0	0	0.725	6.593	1.29	1.586	1.488
1942	0.597	0	0	7.589	0	0	0	0	0	0.95	2.679	2.517
1943	1.321	0.466	0	0	0	0	0	2.98	19.529	2.041	21.641	52.557
1944	3.807	0	0	0	0	0	0	47.196	16.2	42.165	48.385	5.98
1945	9.725	1.857	0	0	0	0	0	0	0	0	0	1.78
1946	0.735	0	0	0	0	0	0	0	0	8.474	1.831	0.992
1947	0.855	0	0	0	0	0	0	0	0	0	0	0
1948	31.081	4.235	0	0	0	0	0	0	0	0	0.292	1.215
1949	0.418	1.868	0	0	0	0	0	0	0	0.379	0.221	1.49
1950	0.905	3.379	0	0	0	0	0	0.034	29.353	22.091	21.725	45.27
1951	5.556	0.116	0	0	0	0	0	0	0	0	5.953	11.219
1952	3.57	12.554	0.192	0	0	0	0	0	0	2.747	1.339	0.778
1953	0.178	0.995	0	0	0	0	0	20.824	5.133	48.429	57.819	5.923
1954	0.98	0	0	0	21.693	0.681	0	0	0	10.772	44.116	5.463
1955	2.979	0.476	0	0	0	0	0	8.428	8.302	3.202	12.123	3.634
1956	2.081	0.063	0.03	0	0	0	0	17.762	37.752	29.047	51.85	8.992
1957	28.589	2.707	0	0	0	0	0	16.36	2.161	0.911	18.978	3.586
1958	1.083	0	0	0	0	0	14.202	8.083	1.145	1.25	18.36	4.057
1959	3.832	0.418	0	0	0	0	0	0	0.298	1.104	0.789	0.584
1960	0.043	0	0	0	0	0	0	0	0	0	1.715	3.907
1961	1.232	0	0	0	0	0	0	0	9.676	1.882	50.282	4.16
1962	12.351	2.18	0	0	0	0	0	0	0	1.829	10.384	1.685
1963	0.346	0	0	0	0	0	0	0	8.126	3.009	18.937	3.986

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1964	1.521	5.633	0.561	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0	0	6.737	2.622
1966	0.813	0	0	0	0	0	10.638	0.947	5.866	2.435	7.665	2.839
1967	1.121	0	0	0	0	0	0	0	1.323	0.9	3.529	1.306
1968	0.648	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	6.264	2.179
1970	1.144	0	0	0	0	0	0	0	0	0	10.253	1.988
1971	1.009	0	0	0	0	0	0	0	0	0.258	7.456	2.669
1972	1.043	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	48.777	6.449
1974	3.652	0.427	0	0	0	0	0	0	0	1.876	7.633	1.801
1975	1.384	0	0	0	0	0	0	0	32.944	7.504	11.241	3.828
1976	2.499	2.158	0	0	0	0	0	1.174	3.128	24.878	22.251	4.314
1977	1.192	0	0.034	0	0	0	0	0	0	0.094	5.453	1.544
1978	0.88	0	0	0	4.661	0.348	0	1.034	1.054	2.021	2.853	1.513
1979	3.14	0.336	0	0	0	0	0	0	0	0	0	0
1980	0	1.58	0	1.673	0	0	2.192	0.26	0	9.033	10.296	7.292
1981	2.028	0.03	0	0	0	0	7.658	0.84	0.843	0.23	0.728	0.441
1982	0	0	0	0	0	0	0	11.132	7.478	8.944	5.255	6.867
1983	1.979	0.013	0	0	0	0	0	6.517	0.786	0.868	0.686	1.888
1984	3.252	0.179	0.12	0	0	0	0	0	0	30.832	4.027	2.191
1985	1.95	0.076	0	0	0	0	0	0	0	0	52.089	6.015
1986	1.694	0.312	0	0	0	0	0	0	0	0	7.727	5.11
1987	1.631	0	0	0	0	0	0	0	0	0	3.072	1.63
1988	0.888	0	0	0	0	3.974	18.09	1.313	11.189	31.58	31.689	15.243
1989	4.681	0.641	0	0	0	0	3.298	3.724	14.167	7.467	3.774	2.323
1990	0.556	0	0	0	0	0	0	0	0	21.901	2.101	1.696
1991	7.631	1.202	0	0	0	0	0	0	0.505	1.434	3.715	6.05
1992	6.51	1.221	0	0	0	0	55.419	1.256	5.589	45.936	17.069	3.721
1993	0.464	0	0	0	0	0	0	0	33.346	4.249	3.652	2.216
1994	0.741	0	0.255	0	0	0	0	3.696	1.095	3.355	13.493	3.036
1995	1.267	0.105	1.936	0	0	0	0	0	0	2.149	1.457	2.195
1996	13.385	3.398	0	0	0	0	0	8.948	3.283	1.279	1.897	1.221
1997	0.343	2.155	0	0	0	0	0	24.741	1.909	1.986	4	2.03
1998	0.202	3.232	25.448	0	0	0	0	0	0	0	0	8.128
1999	1.024	0	0	0	0	0	0	0	0	0	0.349	1.935
2000	0.471	0	0	0	0	0	0	0	0	9.803	6.392	3.246
2001	1.942	0.034	0	1.264	0	0	0	0	1.603	6.811	10.455	4.339
2002	1.721	0	0	0	0	27.454	0.021	1.531	0.201	0.163	39.926	5.437
2003	1.848	0	0	0	0	0	0	0	0	0	0	0
2004	17.138	0.813	0	0	0	0	58.554	5.823	11.4	2.64	3.07	2.129

Scenario 3 Flow out of the Estuary (at the mouth)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0	0	0	0	0	0	0	0	50.663	14.264	26.022	5.484
1921	0.842	0	0	0	0	0	0	0	3.332	0.483	5.037	0.943
1922	0	19.474	0	0	0	0	0	5.851	5.505	8.677	7.049	3.28
1923	1.267	13.145	0	0	0	0	0	0	4.97	0.705	9.469	2.745
1924	0.628	1.609	0	0	0	0	0	0	40.648	4.773	6.256	2.485
1925	2.063	0	0	0	0	0	0	0	0	12.055	3.525	1.743
1926	21.578	3.709	0	0	0	0	0	0	0	0	0	0
1927	0	0	0	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	0	0	0	0	0	0	0
1929	0	0	0	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0	0	11.503	3.212
1931	9.336	0.105	0	0	0	0	0	0	0	0	0	25.134
1932	3.155	0	0	0	0	0	0	0	0	3.019	20.703	3.135
1933	0.066	0	0	0	0	0	0	0	0	0	0	6.58
1934	2.762	0	0	0	0	0	0	0	0	0	0.006	1.375
1935	0.101	0	0	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	0	13.345	3.061	4.547
1937	1.37	0	0	0	0	0	0	0	0	0	0	19.742
1938	4.464	0	0	0	0	0	0	0	0	0	1.683	1.734
1939	0	0	0	0	11.589	2.943	2.37	0.03	5.393	1.817	0.823	1.18
1940	0	0.3	0	0	0	0	2.286	10.419	9.359	8.483	12.451	28.802
1941	3.559	0	0	0	0	0	0	0	4.134	1.486	1.746	1.528
1942	0.123	0	0	5.831	0	0	0	0	0	0	3.092	2.751
1943	0.884	0.007	0	0	0	0	0	0	20.142	2.377	22.863	54.265
1944	3.866	0	0	0	0	0	0	44.778	18.758	43.849	52.978	6.926
1945	11.231	1.436	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	4.108	2.231	0.844
1947	0.41	0	0	0	0	0	0	0	0	0	0	0
1948	34.629	5.233	0	0	0	0	0	0	0	0	0	0
1949	0	0.453	0	0	0	0	0	0	0	0	0	0
1950	0	1.965	0	0	0	0	0	0	28.705	23.154	22.12	49.393
1951	6.204	0	0	0	0	0	0	0	0	0	3.583	13.92
1952	3.809	12.241	0	0	0	0	0	0	0	0	1.563	0.582
1953	0	0	0	0	0	0	0	19.165	6.586	51.774	62.178	6.781
1954	0.709	0	0	0	20.264	0.359	0	0	0	11.175	47.313	6.082
1955	3.249	0	0	0	0	0	0	4.964	10.17	4.338	13.446	3.756
1956	1.988	0	0	0	0	0	0	15.992	40.815	31.22	55.579	10.558
1957	30.898	2.321	0	0	0	0	0	13.863	2.755	0.787	20.271	3.598
1958	0.734	0	0	0	0	0	12.217	9.716	1.231	1.532	19.452	4.191
1959	4.034	0	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0	0	0	0.935
1961	0.916	0	0	0	0	0	0	0	6.247	2.313	51.259	4.158
1962	13.246	1.622	0	0	0	0	0	0	0	0	8.914	1.435
1963	0	0	0	0	0	0	0	0	4.917	3.794	19.643	4.221

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1964	1.208	7.148	0	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0	0	0.722	3.071
1966	0.363	0	0	0	0	0	7.124	1.445	7.528	3.096	7.969	2.689
1967	0.803	0	0	0	0	0	0	0	0	0	2.17	1.159
1968	0.393	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0	0	6.297	2.007
1971	0.573	0	0	0	0	0	0	0	0	0	4.107	2.87
1972	0.518	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	40.016	6.938
1974	3.44	0	0	0	0	0	0	0	0	0	5.36	1.636
1975	1.351	0	0	0	0	0	0	0	32.175	8.88	11.514	3.802
1976	2.256	1.788	0	0	0	0	0	0	2.107	26.213	23.016	4.387
1977	0.742	0	0	0	0	0	0	0	0	0	4.408	1.884
1978	0.606	0	0	0	2.929	0	0	0	1.49	2.467	3.105	1.423
1979	3.891	0	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	9.393	10.834	7.485
1981	1.497	0	0	0	0	0	4.878	1.19	1.354	0.27	1.024	0.506
1982	0	0	0	0	0	0	0	6.742	9.033	9.994	6.284	7.109
1983	1.446	0	0	0	0	0	0	2.855	1.151	1.187	0.664	2.035
1984	3.187	0	0	0	0	0	0	0	0	29.166	4.635	2.027
1985	1.858	0	0	0	0	0	0	0	0	0	53.431	7.751
1986	1.334	0	0	0	0	0	0	0	0	0	4.537	5.36
1987	1.125	0	0	0	0	0	0	0	0	0	0	1.393
1988	0.596	0	0	0	0	0	19.448	1.725	12.451	32.852	34.547	17.375
1989	5.123	0	0	0	0	0	0	3.244	15.317	8.362	3.988	2.213
1990	0.05	0	0	0	0	0	0	0	0	18.722	2.356	1.855
1991	8.81	0.66	0	0	0	0	0	0	0	0	3.763	6.444
1992	7.612	0.725	0	0	0	0	52.539	1.746	6.093	50.068	18.97	3.761
1993	0	0	0	0	0	0	0	0	32.013	5.602	3.874	2.11
1994	0.466	0	0	0	0	0	0	1.236	1.482	4.098	13.903	3.043
1995	1.024	0	0.645	0	0	0	0	0	0	0	1.863	2.669
1996	14.154	3.011	0	0	0	0	0	5.386	4.034	1.345	2.358	0.93
1997	0.143	1.508	0	0	0	0	0	23.272	2.521	2.512	4.232	1.865
1998	0	3.281	25.11	0	0	0	0	0	0	0	0	7.589
1999	0.781	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	3.985	7.59	3.593
2001	1.772	0	0	0	0	0	0	0	0	7.84	11.988	4.867
2002	1.343	0	0	0	0	23.381	0	1.509	0.242	0.28	42.12	6.055
2003	1.421	0	0	0	0	0	0	0	0	0	0	0
2004	13.948	0.266	0	0	0	0	64.146	8.75	12.72	2.882	3.478	2.085

Scenario 4 Flow into Estuary (at Stanford)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0	0	0	0	0	0	0	0	48.934	13.073	25.412	4.809
1921	1.128	0	0	0	0	0	0	0	4.735	0.236	4.55	0.948
1922	0.006	18.976	0.01	0	0	0	0	6.149	4.407	7.793	6.437	2.924
1923	1.05	13.151	0	0	0	0	0	0	6.99	0.228	7.628	2.121
1924	0.619	0.961	0	0	0	0	0	0	42.172	4.119	5.576	2.549
1925	1.916	0	0	0	0	0	0	0	0	12.746	2.621	1.51
1926	17.37	3.143	0	0	0	0	0	0	0	0	0	0.502
1927	0	0	0	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	0	0	0	0	0	0	0
1929	0	0	0	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0	2.931	11.654	2.901
1931	8.652	0.637	0	0	0	0	0	0	0	0	0	22.497
1932	2.562	0	0	0	0	0	0	0	1.437	2.998	19.93	3.009
1933	0.185	0	0	0	0	0	0	0	0	0	0	6.982
1934	2.525	0	0	0	0	0	0	0	0	0.081	0.865	1.073
1935	0.28	0	0	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	0	12.958	2.236	3.933
1937	1.349	0	0	0	0	0	0	0	0	0	0	18.045
1938	3.754	0	0	0	0	0	0	0	0	0	1.52	1.379
1939	0.155	0	0	0	9.493	1.944	1.756	0	3.915	1.164	0.61	0.709
1940	0	0.643	0	0	0	0	3.311	9.233	8.852	7.616	11.924	27.685
1941	3.352	0	0	0	0	0	0	0	4.825	0.986	1.288	1.192
1942	0.261	0	0	6.553	0	0	0	0	0	0	1.524	2.226
1943	0.984	0.138	0	0	0	0	0	0.922	19.287	1.736	21.374	52.288
1944	3.477	0	0	0	0	0	0	44.981	15.957	41.896	48.128	5.667
1945	9.44	1.509	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	4.593	1.533	0.686
1947	0.522	0	0	0	0	0	0	0	0	0	0	0
1948	27.321	3.881	0	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	0	0	0	0	0
1950	0	2.385	0	0	0	0	0	0	27.203	21.811	21.431	45.02
1951	5.218	0	0	0	0	0	0	0	0	0	2.842	10.955
1952	3.239	12.23	0	0	0	0	0	0	0	0.233	1.037	0.468
1953	0	0.506	0	0	0	0	0	18.841	4.868	48.181	57.554	5.616
1954	0.649	0	0	0	20.393	0.322	0	0	0	9.592	43.875	5.158
1955	2.672	0.13	0	0	0	0	0	6.422	8.054	2.928	11.835	3.323
1956	1.762	0	0	0	0	0	0	15.57	37.517	28.772	51.583	8.707
1957	28.306	2.349	0	0	0	0	0	14.359	1.881	0.597	18.712	3.275
1958	0.755	0	0	0	0	0	12.295	7.809	0.847	0.959	18.09	3.755
1959	3.522	0.063	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0	0	0	1.445
1961	0.901	0	0	0	0	0	0	0	7.146	1.588	50.01	3.852
1962	12.057	1.835	0	0	0	0	0	0	0	0	9.294	1.37
1963	0.018	0	0	0	0	0	0	0	5.526	2.722	18.657	3.693

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1964	1.191	5.343	0.18	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0	0	0.553	2.329
1966	0.474	0	0	0	0	0	8.573	0.646	5.621	2.146	7.37	2.53
1967	0.793	0	0	0	0	0	0	0	0	0	2.667	0.996
1968	0.324	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	0	0.25
1970	0.817	0	0	0	0	0	0	0	0	0	7.058	1.687
1971	0.674	0	0	0	0	0	0	0	0	0	4.565	2.376
1972	0.702	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	40.563	6.153
1974	3.329	0.073	0	0	0	0	0	0	0	0	6.589	1.491
1975	1.069	0	0	0	0	0	0	0	30.456	7.219	10.944	3.525
1976	2.174	1.832	0	0	0	0	0	0	2.054	24.613	21.959	4.011
1977	0.855	0	0	0	0	0	0	0	0	0	2.516	1.255
1978	0.551	0	0	0	3.325	0	0	0.163	0.782	1.736	2.558	1.21
1979	2.844	0	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	8.409	10.009	6.999
1981	1.686	0	0	0	0	0	5.665	0.526	0.574	0	0.364	0.146
1982	0	0	0	0	0	0	0	8.476	7.229	8.669	4.967	6.567
1983	1.636	0	0	0	0	0	0	4.191	0.495	0.58	0.378	1.598
1984	2.934	0	0	0	0	0	0	0	0	28.246	3.73	1.882
1985	1.632	0	0	0	0	0	0	0	0	0	48.979	5.724
1986	1.361	0	0	0	0	0	0	0	0	0	4.673	4.818
1987	1.291	0	0	0	0	0	0	0	0	0	0	1.164
1988	0.561	0	0	0	0	2.271	17.823	1.013	10.937	31.307	31.416	14.966
1989	4.367	0.289	0	0	0	0	1.573	3.448	13.911	7.191	3.471	2.015
1990	0.216	0	0	0	0	0	0	0	0	18.98	1.79	1.405
1991	7.342	0.853	0	0	0	0	0	0	0	0	2.784	5.764
1992	6.219	0.875	0	0	0	0	53.716	0.963	5.318	45.709	16.777	3.409
1993	0.121	0	0	0	0	0	0	0	30.752	3.961	3.354	1.91
1994	0.415	0	0	0	0	0	0	1.652	0.817	3.079	13.2	2.735
1995	0.941	0	1.359	0	0	0	0	0	0	0	1.074	1.914
1996	13.087	3.064	0	0	0	0	0	7.034	3.016	0.974	1.612	0.904
1997	0.022	1.819	0	0	0	0	0	22.758	1.625	1.703	3.701	1.72
1998	0	2.758	25.098	0	0	0	0	0	0	0	0	5.325
1999	0.685	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	5.815	6.121	2.955
2001	1.619	0	0	0.257	0	0	0	0	0.144	6.538	10.181	4.048
2002	1.386	0	0	0	0	25.877	0	0.95	0	0	39.447	5.146
2003	1.512	0	0	0	0	0	0	0	0	0	0	0
2004	13.453	0.46	0	0	0	0	56.956	5.536	11.148	2.333	2.78	1.825

Scenario 4 Flow out of the Estuary (at the mouth)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0	0	0	0	0	0	0	0	47.815	13.947	25.734	5.201
1921	0.493	0	0	0	0	0	0	0	0.737	0.174	4.743	0.629
1922	0	19.174	0	0	0	0	0	4.246	5.238	8.394	6.753	2.973
1923	0.943	12.82	0	0	0	0	0	0	2.688	0.408	9.209	2.449
1924	0.3	1.302	0	0	0	0	0	0	38.383	4.477	5.97	2.165
1925	1.744	0	0	0	0	0	0	0	0	9.245	3.231	1.44
1926	21.322	3.362	0	0	0	0	0	0	0	0	0	0
1927	0	0	0	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	0	0	0	0	0	0	0
1929	0	0	0	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0	0	0	0
1931	5.728	0	0	0	0	0	0	0	0	0	0	20.925
1932	2.822	0	0	0	0	0	0	0	0	0	20.42	2.824
1933	0	0	0	0	0	0	0	0	0	0	0	2.505
1934	2.441	0	0	0	0	0	0	0	0	0	0	0
1935	0	0	0	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	0	4.74	2.757	4.261
1937	1.04	0	0	0	0	0	0	0	0	0	0	16.354
1938	4.153	0	0	0	0	0	0	0	0	0	0	0.008
1939	0	0	0	0	10.255	2.598	2.082	0.03	4.837	1.524	0.509	0.89
1940	0	0	0	0	0	0	0	10.142	9.075	8.203	12.153	28.53
1941	3.231	0	0	0	0	0	0	0	1.64	1.181	1.449	1.232
1942	0	0	0	4.268	0	0	0	0	0	0	0.987	2.46
1943	0.548	0	0	0	0	0	0	0	17.279	2.072	22.596	53.996
1944	3.536	0	0	0	0	0	0	42.562	18.515	43.579	52.721	6.612
1945	10.947	1.088	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	0	0	0.341
1947	0.077	0	0	0	0	0	0	0	0	0	0	0
1948	30.869	4.878	0	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	0	0	0	0	0
1950	0	0	0	0	0	0	0	0	21.485	22.873	21.826	49.143
1951	5.867	0	0	0	0	0	0	0	0	0	0	13.658
1952	3.478	11.917	0	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	16.697	6.321	51.526	61.913	6.475
1954	0.379	0	0	0	18.964	0	0	0	0	9.995	47.073	5.777
1955	2.942	0	0	0	0	0	0	2.958	9.921	4.065	13.158	3.445
1956	1.669	0	0	0	0	0	0	13.771	40.58	30.945	55.312	10.274
1957	30.616	1.962	0	0	0	0	0	11.862	2.474	0.474	20.005	3.287
1958	0.405	0	0	0	0	0	10.31	9.441	0.934	1.241	19.182	3.889
1959	3.724	0	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0	0	0.449	50.986	3.85
1962	12.952	1.276	0	0	0	0	0	0	0	0	5.994	1.12
1963	0	0	0	0	0	0	0	0	2.317	3.507	19.363	3.927

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1964	0.877	6.858	0	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	2.531	1.144	7.283	2.807	7.675	2.379
1967	0.476	0	0	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0	0	0.372
1972	0.177	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	31.819	6.642
1974	3.116	0	0	0	0	0	0	0	0	0	2.44	1.327
1975	1.036	0	0	0	0	0	0	0	29.688	8.596	11.217	3.499
1976	1.931	1.462	0	0	0	0	0	0	0	25.806	22.724	4.085
1977	0.405	0	0	0	0	0	0	0	0	0	1.344	1.596
1978	0.277	0	0	0	1.592	0	0	0	0.346	2.182	2.81	1.12
1979	3.595	0	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	3.077	10.547	7.193
1981	1.155	0	0	0	0	0	2.885	0.875	1.085	0.04	0.66	0.211
1982	0	0	0	0	0	0	0	4.086	8.784	9.72	5.995	6.809
1983	1.103	0	0	0	0	0	0	0	0.864	0.899	0.356	1.744
1984	2.87	0	0	0	0	0	0	0	0	26.461	4.337	1.718
1985	1.54	0	0	0	0	0	0	0	0	0	50.321	7.46
1986	1.001	0	0	0	0	0	0	0	0	0	1.484	5.067
1987	0.784	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	15.933	1.425	12.198	32.579	34.274	17.098
1989	4.809	0	0	0	0	0	0	1.242	15.061	8.085	3.685	1.905
1990	0	0	0	0	0	0	0	0	0	15.238	2.046	1.563
1991	8.521	0.311	0	0	0	0	0	0	0	0	0.892	6.158
1992	7.321	0.38	0	0	0	0	50.835	1.453	5.822	49.84	18.677	3.448
1993	0	0	0	0	0	0	0	0	29.419	5.314	3.576	1.804
1994	0.141	0	0	0	0	0	0	0	0	3.824	13.611	2.742
1995	0.699	0	0.068	0	0	0	0	0	0	0	0	1.723
1996	13.856	2.676	0	0	0	0	0	3.471	3.768	1.04	2.073	0.613
1997	0	0.804	0	0	0	0	0	21.29	2.237	2.23	3.933	1.556
1998	0	2.807	24.76	0	0	0	0	0	0	0	0	4.786
1999	0.441	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	4.592	3.303
2001	1.448	0	0	0	0	0	0	0	0	5.614	11.714	4.576
2002	1.008	0	0	0	0	21.804	0	0.929	0.041	0.117	41.641	5.764
2003	1.085	0	0	0	0	0	0	0	0	0	0	0
2004	10.263	0	0	0	0	0	61.585	8.464	12.468	2.575	3.189	1.781

Scenario 5 Flow into Estuary (at Stanford)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0	0	0	0	0	0	0	0	45.066	12.673	25.098	4.492
1921	0.635	0	0	0	0	0	0	0	1.224	0	4.085	0.54
1922	0	18.174	0	0	0	0	0	3.452	4.139	7.497	6.102	2.536
1923	0.629	12.71	0	0	0	0	0	0	3.825	0	7.288	1.766
1924	0.187	0.572	0	0	0	0	0	0	38.996	3.784	5.269	2.121
1925	1.512	0	0	0	0	0	0	0	0	8.991	2.293	1.134
1926	17.157	2.636	0	0	0	0	0	0	0	0	0	0
1927	0	0	0	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	0	0	0	0	0	0	0
1929	0	0	0	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0	0	0	2.172
1931	8.293	0.098	0	0	0	0	0	0	0	0	0	18.488
1932	2.116	0	0	0	0	0	0	0	0	0.491	19.628	2.609
1933	0	0	0	0	0	0	0	0	0	0	0	2.059
1934	2.116	0	0	0	0	0	0	0	0	0	0	0
1935	0	0	0	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	0	2.404	1.874	3.608
1937	0.909	0	0	0	0	0	0	0	0	0	0	13.625
1938	3.371	0	0	0	0	0	0	0	0	0	0	0
1939	0	0	0	0	5.984	1.463	1.426	0	3.304	0.835	0.22	0.373
1940	0	0	0	0	0	0	0.657	8.931	8.534	7.329	11.582	27.401
1941	2.922	0	0	0	0	0	0	0	1.424	0.625	0.948	0.836
1942	0	0	0	4.826	0	0	0	0	0	0	0	0.796
1943	0.528	0	0	0	0	0	0	0	16.844	1.372	21.125	52.015
1944	3.04	0	0	0	0	0	0	41.759	15.761	41.639	47.91	5.261
1945	9.139	1.001	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	0	0	0	0	0	0
1948	20.759	3.352	0	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	0	0	0	0	0
1950	0	0	0	0	0	0	0	0	17.605	21.522	21.103	44.803
1951	4.757	0	0	0	0	0	0	0	0	0	0	9.335
1952	2.798	11.79	0	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	13.668	4.606	47.988	57.311	5.23
1954	0.211	0	0	0	18.455	0	0	0	0	7.799	43.706	4.778
1955	2.301	0	0	0	0	0	0	3.301	7.843	2.661	11.525	2.923
1956	1.358	0	0	0	0	0	0	12.471	37.346	28.501	51.336	8.386
1957	28.011	1.806	0	0	0	0	0	11.647	1.573	0.208	18.468	2.875
1958	0.32	0	0	0	0	0	9.486	7.538	0.487	0.64	17.832	3.381
1959	3.146	0	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0	0	0	47.927	3.46
1962	11.728	1.331	0	0	0	0	0	0	0	0	5.479	0.957
1963	0	0	0	0	0	0	0	0	1.678	2.413	18.37	3.346

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1964	0.752	5.007	0	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0.323	0.296	5.419	1.832	7.039	2.134
1967	0.362	0	0	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	31.373	5.799
1974	2.911	0	0	0	0	0	0	0	0	0	2.356	1.095
1975	0.676	0	0	0	0	0	0	0	26.984	6.919	10.605	3.15
1976	1.751	1.387	0	0	0	0	0	0	0	23.424	21.635	3.636
1977	0.394	0	0	0	0	0	0	0	0	0	0	0
1978	0	0	0	0	0.911	0	0	0	0	1.063	2.226	0.833
1979	2.509	0	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	0.243	9.701	6.655
1981	1.213	0	0	0	0	0	2.844	0.135	0.299	0	0	0
1982	0	0	0	0	0	0	0	4.377	7.014	8.398	4.654	6.202
1983	1.159	0	0	0	0	0	0	0.981	0.156	0.268	0.007	1.259
1984	2.535	0	0	0	0	0	0	0	0	24.598	3.39	1.491
1985	1.232	0	0	0	0	0	0	0	0	0	44.852	5.385
1986	0.914	0	0	0	0	0	0	0	0	0	0.655	4.474
1987	0.822	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	14.271	0.665	10.713	31.041	31.15	14.668
1989	3.976	0	0	0	0	0	0	1.889	13.674	6.914	3.112	1.624
1990	0	0	0	0	0	0	0	0	0	14.823	1.412	1.064
1991	7.027	0.339	0	0	0	0	0	0	0	0	0	4.549
1992	5.897	0.372	0	0	0	0	51.342	0.636	5.038	45.578	16.451	3.004
1993	0	0	0	0	0	0	0	0	26.983	3.651	3.013	1.525
1994	0	0	0	0	0	0	0	0	0	1.671	12.875	2.366
1995	0.518	0	0.396	0	0	0	0	0	0	0	0	0
1996	12.179	2.592	0	0	0	0	0	4.266	2.749	0.612	1.308	0.486
1997	0	0.958	0	0	0	0	0	20.098	1.305	1.407	3.358	1.324
1998	0	1.957	24.601	0	0	0	0	0	0	0	0	1.799
1999	0.218	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	3.14	2.617
2001	1.202	0	0	0	0	0	0	0	0	3.225	9.912	3.707
2002	0.932	0	0	0	0	23.365	0	0.233	0	0	38.555	4.804
2003	1.056	0	0	0	0	0	0	0	0	0	0	0
2004	8.491	0	0	0	0	0	54.388	5.23	10.924	1.966	2.465	1.446

Scenario 5 Flow out of the Estuary (at the mouth)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0	0	0	0	0	0	0	0	45.066	12.673	25.098	4.492
1921	0.635	0	0	0	0	0	0	0	1.224	0	4.085	0.54
1922	0	18.174	0	0	0	0	0	3.452	4.139	7.497	6.102	2.536
1923	0.629	12.71	0	0	0	0	0	0	3.825	0	7.288	1.766
1924	0.187	0.572	0	0	0	0	0	0	38.996	3.784	5.269	2.121
1925	1.512	0	0	0	0	0	0	0	0	8.991	2.293	1.134
1926	17.157	2.636	0	0	0	0	0	0	0	0	0	0
1927	0	0	0	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	0	0	0	0	0	0	0
1929	0	0	0	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0	0	0	2.172
1931	8.293	0.098	0	0	0	0	0	0	0	0	0	18.488
1932	2.116	0	0	0	0	0	0	0	0	0.491	19.628	2.609
1933	0	0	0	0	0	0	0	0	0	0	0	2.059
1934	2.116	0	0	0	0	0	0	0	0	0	0	0
1935	0	0	0	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	0	2.404	1.874	3.608
1937	0.909	0	0	0	0	0	0	0	0	0	0	13.625
1938	3.371	0	0	0	0	0	0	0	0	0	0	0
1939	0	0	0	0	5.984	1.463	1.426	0	3.304	0.835	0.22	0.373
1940	0	0	0	0	0	0	0.657	8.931	8.534	7.329	11.582	27.401
1941	2.922	0	0	0	0	0	0	0	1.424	0.625	0.948	0.836
1942	0	0	0	4.826	0	0	0	0	0	0	0	0.796
1943	0.528	0	0	0	0	0	0	0	16.844	1.372	21.125	52.015
1944	3.04	0	0	0	0	0	0	41.759	15.761	41.639	47.91	5.261
1945	9.139	1.001	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	0	0	0	0	0	0
1948	20.759	3.352	0	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	0	0	0	0	0
1950	0	0	0	0	0	0	0	0	17.605	21.522	21.103	44.803
1951	4.757	0	0	0	0	0	0	0	0	0	0	9.335
1952	2.798	11.79	0	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	13.668	4.606	47.988	57.311	5.23
1954	0.211	0	0	0	18.455	0	0	0	0	7.799	43.706	4.778
1955	2.301	0	0	0	0	0	0	3.301	7.843	2.661	11.525	2.923
1956	1.358	0	0	0	0	0	0	12.471	37.346	28.501	51.336	8.386
1957	28.011	1.806	0	0	0	0	0	11.647	1.573	0.208	18.468	2.875
1958	0.32	0	0	0	0	0	9.486	7.538	0.487	0.64	17.832	3.381
1959	3.146	0	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0	0	0	47.927	3.46
1962	11.728	1.331	0	0	0	0	0	0	0	0	5.479	0.957
1963	0	0	0	0	0	0	0	0	1.678	2.413	18.37	3.346

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1964	0.752	5.007	0	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0.323	0.296	5.419	1.832	7.039	2.134
1967	0.362	0	0	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	31.373	5.799
1974	2.911	0	0	0	0	0	0	0	0	0	2.356	1.095
1975	0.676	0	0	0	0	0	0	0	26.984	6.919	10.605	3.15
1976	1.751	1.387	0	0	0	0	0	0	0	23.424	21.635	3.636
1977	0.394	0	0	0	0	0	0	0	0	0	0	0
1978	0	0	0	0	0.911	0	0	0	0	1.063	2.226	0.833
1979	2.509	0	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	0.243	9.701	6.655
1981	1.213	0	0	0	0	0	2.844	0.135	0.299	0	0	0
1982	0	0	0	0	0	0	0	4.377	7.014	8.398	4.654	6.202
1983	1.159	0	0	0	0	0	0	0.981	0.156	0.268	0.007	1.259
1984	2.535	0	0	0	0	0	0	0	0	24.598	3.39	1.491
1985	1.232	0	0	0	0	0	0	0	0	0	44.852	5.385
1986	0.914	0	0	0	0	0	0	0	0	0	0.655	4.474
1987	0.822	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	14.271	0.665	10.713	31.041	31.15	14.668
1989	3.976	0	0	0	0	0	0	1.889	13.674	6.914	3.112	1.624
1990	0	0	0	0	0	0	0	0	0	14.823	1.412	1.064
1991	7.027	0.339	0	0	0	0	0	0	0	0	0	4.549
1992	5.897	0.372	0	0	0	0	51.342	0.636	5.038	45.578	16.451	3.004
1993	0	0	0	0	0	0	0	0	26.983	3.651	3.013	1.525
1994	0	0	0	0	0	0	0	0	0	1.671	12.875	2.366
1995	0.518	0	0.396	0	0	0	0	0	0	0	0	0
1996	12.179	2.592	0	0	0	0	0	4.266	2.749	0.612	1.308	0.486
1997	0	0.958	0	0	0	0	0	20.098	1.305	1.407	3.358	1.324
1998	0	1.957	24.601	0	0	0	0	0	0	0	0	1.799
1999	0.218	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	3.14	2.617
2001	1.202	0	0	0	0	0	0	0	0	3.225	9.912	3.707
2002	0.932	0	0	0	0	23.365	0	0.233	0	0	38.555	4.804
2003	1.056	0	0	0	0	0	0	0	0	0	0	0
2004	8.491	0	0	0	0	0	54.388	5.23	10.924	1.966	2.465	1.446

Scenario 6 Flow into Estuary (at Stanford)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0	0	0	0	0	0	0	0	42.199	12.379	24.86	4.254
1921	0.278	0	0	0	0	0	0	0	0	0	2.179	0.24
1922	0	17.58	0	0	0	0	0	1.48	3.932	7.271	5.85	2.251
1923	0.319	12.388	0	0	0	0	0	0	1.472	0	6.853	1.501
1924	0	0.01	0	0	0	0	0	0	36.651	3.532	5.035	1.808
1925	1.214	0	0	0	0	0	0	0	0	6.117	2.046	0.856
1926	16.986	2.271	0	0	0	0	0	0	0	0	0	0
1927	0	0	0	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	0	0	0	0	0	0	0
1929	0	0	0	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	0	0	0	0	0	0	10.293
1932	1.79	0	0	0	0	0	0	0	0	0	16.953	2.315
1933	0	0	0	0	0	0	0	0	0	0	0	0
1934	0.089	0	0	0	0	0	0	0	0	0	0	0
1935	0	0	0	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	0	0	0	0
1937	0	0	0	0	0	0	0	0	0	0	0	8.554
1938	3.087	0	0	0	0	0	0	0	0	0	0	0
1939	0	0	0	0	1.054	1.113	1.179	0	2.842	0.588	0	0
1940	0	0	0	0	0	0	0	6.974	8.295	7.109	11.325	27.184
1941	2.607	0	0	0	0	0	0	0	0	0	0	0.459
1942	0	0	0	3.504	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	0	13.119	1.102	20.931	51.806
1944	2.721	0	0	0	0	0	0	39.382	15.602	41.439	47.736	4.962
1945	8.91	0.634	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	0	0	0	0	0	0
1948	10.57	2.971	0	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	0	0	0	0	0
1950	0	0	0	0	0	0	0	0	8.428	21.301	20.856	44.631
1951	4.422	0	0	0	0	0	0	0	0	0	0	6.032
1952	2.476	11.469	0	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	8.156	4.404	47.832	57.121	4.945
1954	0	0	0	0	16.751	0	0	0	0	6.63	43.565	4.498
1955	2.026	0	0	0	0	0	0	0.974	7.675	2.455	11.289	2.628
1956	1.06	0	0	0	0	0	0	10.191	37.204	28.292	51.143	8.144
1957	27.786	1.417	0	0	0	0	0	9.653	1.341	0	18.131	2.582
1958	0.002	0	0	0	0	0	7.417	7.329	0.22	0.398	17.631	3.105
1959	2.867	0	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0	0	0	37.865	3.172
1962	11.481	0.967	0	0	0	0	0	0	0	0	2.656	0.655
1963	0	0	0	0	0	0	0	0	0	0.991	18.151	3.087

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1964	0.431	4.756	0	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0	0	0	0	5.31	1.843
1967	0.047	0	0	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	18.118	5.536
1974	2.604	0	0	0	0	0	0	0	0	0	0	0
1975	0.185	0	0	0	0	0	0	0	24.433	6.69	10.35	2.872
1976	1.44	1.064	0	0	0	0	0	0	0	21.018	21.392	3.359
1977	0.059	0	0	0	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0	0	0	0	0
1979	0.581	0	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	0	3.294	6.398
1981	0.869	0	0	0	0	0	0.762	0	0	0	0	0
1982	0	0	0	0	0	0	0	0.883	6.844	8.19	4.418	5.931
1983	0.813	0	0	0	0	0	0	0	0	0	0	0
1984	1.523	0	0	0	0	0	0	0	0	21.845	3.135	1.203
1985	0.937	0	0	0	0	0	0	0	0	0	41.832	5.131
1986	0.588	0	0	0	0	0	0	0	0	0	0	1.795
1987	0.482	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	8.653	0.405	10.536	30.835	30.944	14.442
1989	3.687	0	0	0	0	0	0	0	13.217	6.7	2.845	1.336
1990	0	0	0	0	0	0	0	0	0	11.674	1.132	0.81
1991	6.789	0	0	0	0	0	0	0	0	0	0	1.054
1992	5.654	0.009	0	0	0	0	49.596	0.39	4.824	45.462	16.205	2.707
1993	0	0	0	0	0	0	0	0	24.12	3.416	2.757	1.241
1994	0	0	0	0	0	0	0	0	0	0	11.435	2.092
1995	0.207	0	0	0	0	0	0	0	0	0	0	0
1996	8.895	2.251	0	0	0	0	0	2.228	2.543	0.342	1.077	0.18
1997	0	0.313	0	0	0	0	0	18.143	1.064	1.182	3.101	1.033
1998	0	1.342	24.241	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	9.091	3.452
2002	0.602	0	0	0	0	21.514	0	0	0	0	37.577	4.549
2003	0.723	0	0	0	0	0	0	0	0	0	0	0
2004	4.799	0	0	0	0	0	52.709	4.998	10.748	1.693	2.226	1.166

Scenario 6 Flow out of the Estuary (at the mouth)

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0	0	0	0	0	0	0	0	41.08	13.253	25.182	4.646
1921	0	0	0	0	0	0	0	0	0	0	0	0
1922	0	15.371	0	0	0	0	0	0	4.34	7.873	6.166	2.3
1923	0.212	12.058	0	0	0	0	0	0	0	0	5.781	1.829
1924	0	0	0	0	0	0	0	0	32.805	3.89	5.429	1.424
1925	1.043	0	0	0	0	0	0	0	0	2.616	2.656	0.786
1926	20.938	2.489	0	0	0	0	0	0	0	0	0	0
1927	0	0	0	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	0	0	0	0	0	0	0
1929	0	0	0	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	0	0	0	0	0	0	0
1932	0	0	0	0	0	0	0	0	0	0	3.647	2.131
1933	0	0	0	0	0	0	0	0	0	0	0	0
1934	0	0	0	0	0	0	0	0	0	0	0	0
1935	0	0	0	0	0	0	0	0	0	0	0	0
1936	0	0	0	0	0	0	0	0	0	0	0	0
1937	0	0	0	0	0	0	0	0	0	0	0	0
1938	0	0	0	0	0	0	0	0	0	0	0	0
1939	0	0	0	0	0	0	0	0	2.866	0.948	0	0
1940	0	0	0	0	0	0	0	4.438	8.518	7.696	11.554	28.028
1941	2.486	0	0	0	0	0	0	0	0	0	0	0
1942	0	0	0	0	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	0	8.909	1.438	22.153	53.514
1944	2.78	0	0	0	0	0	0	36.964	18.16	43.123	52.33	5.908
1945	10.417	0.213	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	0	0	0	0	0	0
1948	7.349	3.969	0	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	0	0	0	0	0	0	0	0
1950	0	0	0	0	0	0	0	0	0	22.367	21.251	48.754
1951	5.07	0	0	0	0	0	0	0	0	0	0	6.361
1952	2.716	11.156	0	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	3.791	5.857	51.177	61.48	5.804
1954	0	0	0	0	14.931	0	0	0	0	6.124	46.763	5.117
1955	2.296	0	0	0	0	0	0	0	7.049	3.591	12.612	2.75
1956	0.967	0	0	0	0	0	0	8.392	40.267	30.465	54.872	9.711
1957	30.095	1.031	0	0	0	0	0	7.155	1.934	0	19.17	2.594
1958	0	0	0	0	0	0	5.036	8.962	0.306	0.68	18.723	3.239
1959	3.069	0	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0	0	0	28.226	3.17
1962	12.376	0.409	0	0	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0	0	0	0	17.099	3.321
1964	0.118	6.271	0	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0	0	0	0	0	0.755

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1967	0	0	0	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	17.021	8.066	10.623	2.846
1976	1.197	0.694	0	0	0	0	0	0	0	20.154	22.157	3.433
1977	0	0	0	0	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	0	0	4.047
1981	0.338	0	0	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	4.268	9.24	5.447	6.172
1983	0.28	0	0	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	18.796	3.743	1.039
1985	0.845	0	0	0	0	0	0	0	0	0	43.175	6.867
1986	0.228	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	1.718	0.817	11.798	32.107	33.802	16.575
1989	4.129	0	0	0	0	0	0	0	10.584	7.595	3.059	1.226
1990	0	0	0	0	0	0	0	0	0	7.932	1.388	0.968
1991	7.967	0	0	0	0	0	0	0	0	0	0	0
1992	5.419	0	0	0	0	0	45.886	0.88	5.328	49.594	18.105	2.746
1993	0	0	0	0	0	0	0	0	22.787	4.768	2.978	1.134
1994	0	0	0	0	0	0	0	0	0	0	9.916	2.099
1995	0	0	0	0	0	0	0	0	0	0	0	0
1996	6.916	1.863	0	0	0	0	0	0	1.959	0.408	1.538	0
1997	0	0	0	0	0	0	0	15.732	1.676	1.708	3.333	0.869
1998	0	1.392	23.903	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	1.642	3.98
2002	0.224	0	0	0	0	17.441	0	0	0.019	0.117	39.77	5.167
2003	0.296	0	0	0	0	0	0	0	0	0	0	0
2004	1.609	0	0	0	0	0	57.337	7.925	12.067	1.935	2.635	1.122

10 APPENDIX C: TEMPLATE FOR PRESENTATION OF RESULTS AS REQUIRED BY THE DWS

1. Description of the River

River:	Klein River
Drainage Region (monitoring point for Reserve):	At head of estuary, approximately 9.5 km from the mouth (34°26'8.21"S; 19°28'22.78"E), alternatively at monitoring station G4H006 (approximately 14 km upstream of the estuary (34°24'21.89"S; 19°36'5.02"E)
Water Management Area:	Breede-Gouritz WMA

2. Preliminary determination of the recommended Ecological Flow Requirement Scenario - Section 17(1)

MAR of 49.43 million cubic meters, 92.6% of the Natural MAR (53.41 million cubic meters)

NOTE: This amount accounts for the Ecological Requirements only

3. Preliminary determination of the Ecological Requirements for Water Quality - Section 17(1)

Not determined as part of a Preliminary Determination of the Ecological Reserve on a Rapid level.

4. Preliminary determination of Recommended Ecological Category

Recommended Ecological Category is Category B.

Category B represents 'Largely natural with few modifications'.

5. Applicability

5.1 This preliminary determination of the Reserve in terms of section(1)(a) is applicable to the following water resources or part of the resource:

Orange Estuary within the following geographical boundaries (WGS84):

- Downstream boundary: The estuary mouth (34°24'58"S 19°17'35"E)
- Upstream boundary: Limit of saline effect, approximately 17.5 km from the mouth (34°26'8.21"S; 19°28'22.78"E)
- Lateral boundaries: 5 m contour above MSL along the banks.

5.2 This preliminary determination of the Reserve in terms of section 17(1)(b) is applicable to the authorising of following water use:

- Section 21(a) - taking water from a water resource
- Section 21 (b) - storing water
- Section 21 (c) - impeding or diverting the flow of water in a watercourse
- Section 21 (e) – engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1)
- Section 21(f) – discharging water into a water resource through a pipe, canal, sewer, sea outfall or other conduit
- Section 21(g) - disposing of waste in a manner which may detrimentally impact on a water resource

- Section 21(h) - disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process
- Section 21 (i) - altering the bed, banks, course or characteristics of a watercourse

6. Supporting Documentation

Supporting documentation is provided in the following Annexures:

Annexure A: Preliminary Ecological Flow Requirement – Water Quantity	X
Annexure B: Preliminary Ecological Requirement – Water Quality	
Annexure C: Preliminary Basic Human Needs	
Annexure D: Resource Quality Objectives	
Annexure E: Special conditions and limitations	
Annexure F: Background and record of decision	X
Annexure G: Methodology	
Annexure H: Specialist reports	
Annexure I: Map of study area	X

ANNEXURE A

PRELIMINARY ECOLOGICAL RESERVE – WATER QUANTITY

1) Level of confidence of the determination: Low (i.e. < 40%)
2) The flow requirement is based on the natural flow contribution of the catchments upstream of the head of the Orange Estuary (34°26'8.21"S; 19°28'22.78"E, approximately 17.5 km upstream of the mouth).
3) Table 1 provides a summary of flow distribution (mean monthly flows in m3/s) of the recommended Ecological Flow Requirement Scenario for the Klein Estuary to meet the recommended Ecological Category of B.
4) Table 2 provides a simulated monthly runoff (in mean monthly m3/s) of the recommended Ecological Flow

Table 1. Summary of the monthly flow (distribution in Mm^3) of the recommended Ecological Flow Requirement Scenario to meet the recommended category of B.

Month	Flow (Mm^3) – flow should be ≥value in given month											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	31.86996	15.85168	6.82348	3.78748	16.33256	10.99668	62.07284	33.07472	52.09756	50.2228	60.37216	50.09532
90%ile	8.2754	3.933	0.638	0.1666	0.1362	0.3282	3.728	10.6746	14.8056	22.8882	31.644	9.7088
80%ile	4.3728	1.9586	0.192	0	0	0.1162	0.8012	3.5836	8.6336	9.4298	19.2116	6.5028
70%ile	2.683	1.0472	0.1046	0	0	0	0.31	1.495	5.1348	5.1652	11.852	4.8286
60%ile	2.2786	0.7646	0.0746	0	0	0	0.117	0.593	2.578	3.7004	8.6844	4.007
50%ile	1.786	0.521	0.053	0	0	0	0.029	0.388	1.214	2.533	6.107	3.255
40%ile	1.5044	0.4394	0.0366	0	0	0	0	0.151	0.7078	1.821	4.3002	2.6678
30%ile	1.1952	0.3604	0.0244	0	0	0	0	0.0586	0.3022	1.4138	2.6404	2.21
20%ile	0.935	0.2876	0.0024	0	0	0	0	0	0.2274	0.9148	1.6672	1.7758
10%ile	0.5814	0.1934	0	0	0	0	0	0	0.0758	0.4978	0.737	1.2982
1%ile	0.32588	0.06452	0	0	0	0	0	0	0	0.10384	0.35336	0.42724

It is estimated that to maintain the estuary in its Present Ecological State of a C, a flow distribution represented by the Present Day (MAR = 40.88) is required:

Month	Flow (Mm^3) – flow should be ≥value in given month											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	29.29652	14.79684	6.14732	3.30052	14.16408	10.02728	58.16036	30.572	48.8652	46.43764	55.36004	46.62288
90%ile	7.4614	3.424	0.5546	0.1396	0.1092	0.2832	3.2316	9.6796	13.5538	21.0654	29.5392	8.6726
80%ile	3.983	1.6808	0.1596	0	0	0.0858	0.6812	3.0256	7.8214	8.5016	17.5998	5.8972
70%ile	2.4588	0.9188	0.0808	0	0	0	0.2654	1.2508	4.653	4.673	10.6216	4.4816
60%ile	2.068	0.6774	0.0544	0	0	0	0.0798	0.5118	2.1826	3.2032	7.5084	3.6204
50%ile	1.614	0.486	0.036	0	0	0	0.015	0.317	1.021	2.284	5.527	2.93
40%ile	1.3244	0.4044	0.0206	0	0	0	0	0.1206	0.5686	1.6074	3.8846	2.4344
30%ile	1.0556	0.3314	0.0068	0	0	0	0	0.0464	0.2634	1.188	2.2166	2.0056
20%ile	0.8048	0.261	0	0	0	0	0	0	0.1868	0.8062	1.4772	1.6248
10%ile	0.486	0.1684	0	0	0	0	0	0	0.0554	0.4274	0.6526	1.1446
1%ile	0.29252	0.04804	0	0	0	0	0	0	0	0.08332	0.31832	0.37824

Table 2. Klein estuary – Simulated runoff (Mm3 per month) for the recommended Ecological Flow Requirement Scenario to meet the recommended Ecological Category of B.

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.41	0.145	0.009	0	0	0	0.029	0	59.671	15.174	27.504	5.787
1921	2.112	0.34	0.026	0.453	0.051	0.148	0	0	10.773	0.982	5.562	1.767
1922	0.834	21.163	1.102	0	0	0	2.538	8.929	5.39	9.272	7.734	3.906
1923	1.976	14.84	0.668	0	0	0	0	0	13.165	0.933	8.989	3.052
1924	1.502	1.912	0.483	0	0	0	0	0	50.655	5.117	6.772	3.501
1925	2.82	0.835	0.053	0	0	0	0	0	0.143	20.889	3.579	2.347
1926	20.095	4.587	0.131	0	0	0	0	0.583	0.415	0.273	6.304	1.306
1927	0.444	0.219	0.021	0	0	0	0	0	1.107	0.082	0.54	1.348
1928	0.432	0.298	0.021	0	0	0	0	0	0.077	8.519	2.102	1.347
1929	0.537	0.162	0.03	0	0	0.058	0	0.124	0.075	0.114	3.654	5.36
1930	1.506	0.502	0.037	0	0	0	4.048	0.484	0.113	7.875	13.555	3.863
1931	10.154	1.697	0.086	0	0	0	0	0.276	0.923	0.922	0.764	29.672
1932	3.757	0.393	0.018	0	0	0	0	0.086	8.331	4.002	22.221	3.937
1933	1.044	0.236	0	0	0	0	0	0	0	1.708	6.98	8.723
1934	3.513	0.93	0.036	0	0	0	0.262	3.218	1.734	2.297	1.69	1.858
1935	1.16	0.655	0.028	0.139	0	0	0	0.386	0.238	0.634	0.719	1.447
1936	0.815	0.788	0.224	0	0	0	0	0	5.68	19.95	3.243	4.947
1937	2.302	0.424	0.059	0	0	0.243	0.259	1.194	0.626	1.05	2.559	22.407
1938	4.852	0.909	0.09	0	0.177	0.043	0.081	0.142	0.107	1.815	6.889	2.298
1939	1.046	0.288	0.003	0	14.602	3.341	2.667	0.388	5.176	1.966	1.43	1.471
1940	0.789	1.741	0.147	0	0	0	8.668	10.65	10.166	8.994	13.323	29.939
1941	4.404	0.749	0.112	0	0	0	0	4.314	7.545	1.825	2.069	1.988
1942	1.154	0.185	0.28	9.397	0.407	0.195	0.157	0.836	0.485	1.628	3.246	3.129
1943	1.93	1.04	0.121	0	0	0	0	6.66	21.353	2.663	23.709	55.977
1944	4.616	0.481	0.046	0	0	0	0.051	53.942	17.987	45.183	52.34	7.117
1945	11.01	2.661	0.128	0	0	1.16	0.046	0	0.281	0.468	0.547	4.112
1946	1.327	0.206	0	0	0	0.116	0	0.048	0.123	13.39	2.412	1.487
1947	1.401	0.358	0	0	0	0.465	0.133	0	0.346	1.845	0.704	0.998
1948	35.592	5.618	0.08	0	0	0	1.096	0.442	0.275	0.547	2.615	1.753
1949	0.957	2.547	0.184	0	0	0	0.32	0	0	4.095	0.717	2.072
1950	1.473	4.146	0.31	0.709	0	0	1.732	0.508	31.744	24.221	23.322	48.975
1951	6.71	0.634	0.054	0	0	0	0	0.157	0.282	2.223	8.748	13.12
1952	4.461	13.867	0.834	0	0	0	1.688	0.412	0.759	3.862	1.873	1.293
1953	0.709	1.6	0.057	0	0	0	0.111	25.944	6.041	52.369	62.221	6.97
1954	1.562	0.399	0.038	0	25.418	1.449	0	0	1.214	11.845	47.754	6.386
1955	3.659	1.105	0.088	0	0	0	0	12.602	9.404	3.88	13.951	4.396
1956	2.685	0.607	0.593	0.054	0	0	0	21.857	40.93	31.466	55.763	10.366
1957	31.161	3.651	0.073	0	0	0.295	0.131	20.341	2.747	1.402	20.844	4.286
1958	1.633	0.447	0.007	0	0	0	18.832	9.245	1.658	1.694	20.33	4.755
1959	4.557	1.049	0.053	0	0	0	0	0.319	4.036	1.57	1.283	1.067
1960	0.528	0.073	0.078	0.518	0.04	0	0	0.139	0.631	0.886	4.52	4.678
1961	1.83	0.424	0	0	0	0.163	0.336	0.098	13.584	2.435	53.8	4.847
1962	13.764	2.939	0.168	0	0	0	0	0.056	0.139	5.758	11.88	2.254
1963	0.847	0.286	0.081	0	0	0.026	0	0	12.695	3.686	20.91	4.626
1964	2.111	6.805	1.36	0	0	0.117	0.069	0.619	0.301	0.694	0.809	0.669
1965	0.648	0.162	0	0	0	0	0.103	0.051	0.021	1.461	11.398	3.309
1966	1.406	0.238	0	0	0	0	15.081	1.504	6.733	3.051	8.835	3.466
1967	1.671	0.48	0.037	0	0	0	0	0.433	4.97	1.364	4.281	1.861
1968	1.175	0.352	0	0	0	0	0.37	0.039	0.303	0.219	0.329	0.334
1969	0.392	0.114	0	0	0	0	0	0	1.151	2.533	10.049	2.83
1970	1.756	0.37	0	0	0	0	0	0	0.453	2.594	13.257	2.545
1971	1.574	0.405	0.073	0	0	0	1.526	0.608	1.047	1.18	8.642	3.255
1972	1.638	0.288	0	0	0	0	0	0.013	0	0.419	0.358	0.569
1973	0.32	0.065	0	0	0	0	0	2.398	0.302	0.182	56.249	7.55
1974	4.365	1.034	0.046	0	0	0	0	2.33	0.233	3.658	8.825	2.361
1975	1.94	0.464	0	0	0	0	0.674	0.494	38.532	8.785	12.517	4.464
1976	3.12	2.833	0.351	0	0.672	0.04	0.017	3.401	3.756	27.277	23.984	4.994
1977	1.786	0.428	0.764	0.086	0	0	0	0	0	3.722	6.49	2.093
1978	1.457	0.35	0.028	0	7.22	1.075	0	2.095	1.501	2.534	3.468	2.035
1979	3.894	0.967	0.016	0	0	0	0	0.103	3.035	0.473	0.57	0.445
1980	0.327	2.828	0.533	2.719	0.518	0.321	3.248	0.74	0.284	10.061	11.74	8.272
1981	2.675	0.521	0.05	0	0	0	11.554	1.459	1.261	0.661	1.153	0.895
1982	0.373	0.062	0	0	0.444	0.062	0	15.378	8.441	10.24	6.107	7.965
1983	2.637	0.507	0.035	0	0	0	0	10.691	1.317	1.289	1.149	2.411
1984	3.94	0.719	0.877	0.457	0.075	0.021	0.519	0.165	0.205	34.727	4.851	2.757
1985	2.548	0.589	0.041	0	0	0.142	0	0	0.256	0.558	60.02	7.222
1986	2.305	0.824	0.105	0	0	0	0.79	0.527	1.623	1.163	8.982	6.001
1987	2.263	0.303	0	0	0	0	0.701	0.371	0.983	0.563	5.64	2.187
1988	1.441	0.371	0	0	0	7.045	19.876	1.887	12.404	34.039	34.404	17.068
1989	5.55	1.286	0.112	0	0	0	6.276	4.492	15.62	8.561	4.424	2.896
1990	1.121	0.335	0.026	0	0	0	0	0.169	1.076	26.656	2.742	2.199
1991	8.737	1.958	0.058	0	0	0	0.126	0.874	3.326	1.963	4.451	7.055
1992	7.583	1.961	0.103	0	0.008	0	61.273	1.798	6.288	49.814	18.932	4.453
1993	1.014	0.213	0.024	0	0	0	0.148	0.374	39.482	5.176	4.313	2.795
1994	1.276	0.277	1.124	0.112	0	1.079	0.423	5.106	1.552	3.967	15.246	3.634
1995	1.829	0.609	2.863	0.118	0	0	0	0	0.78	5.122	1.992	2.757
1996	14.985	4.213	0.445	0	0	0	0.032	12.534	3.884	1.775	2.392	1.778
1997	0.846	2.839	0.077	0	0	0	0.846	29.1	2.52	2.485	4.742	2.615
1998	0.71	4.121	27.616	0.185	0	0	0.27	0.09	0.068	0.108	1.576	10.813
1999	1.705	0.229	0	0	0	0.333	0.02	0	0.042	3.33	1.247	2.541
2000	1.042	0.182	0	0	0	0	0	0.069	0.011	15.087	7.401	3.885
2001	2.554	0.546	0.021	2.629	0.498	0	0	1.212	2.665	7.782	12.056	5.1
2002	2.339	0.515	0.045	0	0	31.743	0.508	2.024	0.586	0.535	42.814	6.333
2003	2.482	0.494	0.034	0	0	0	0.032	0	0.176	1.677	0.715	0.573
2004	20.79	1.511	0.068	0.396	0	0	66.272	7.325	12.554	3.254	3.66	2.703

ANNEXURE F
BACKGROUND AND RECORD OF DECISION

1) Project Management

Cape Nature: Pierre De Villiers

2) Compilation of the Rapid RDM Specialist Report

Anchor Environmental Consultants: Dr Barry Clark

3) Consultants conducting the Ecological Reserve Study

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4) Motivation for the preliminary Ecological Reserve determination study on a Rapid level

The Breede-Gouritz Overberg Catchment Management Agency, CapeNature and the Klein Estuary Management Forum (stakeholders) were the primary drivers for the determination of the ecological water requirements for the Klein estuary. The Klein Estuary is one of 289 functional estuaries in South Africa (Turpie 2004, Turpie et al. 2010). It covers an area of 2959 ha and is considered to be very important in terms of its conservation value. 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). It was ranked 5th most important in South Africa in terms of its botanical, fish and bird biodiversity (Turpie & Clark 2007). However, it is negatively impacted by flow reduction (abstraction/ impoundment for irrigation and alien infestation in the catchment and riparian areas), increased nutrient loading (waste water treatment works, septic tanks and agricultural return flow and effluent), sedimentation and illegal gill-netting of fish. The Klein River Estuary has therefore been relegated to the C category in terms of its current estuarine health, but allocated a B in terms of the Recommended Ecological category, or future health class, since it is considered worthy of rehabilitation and a priority for conservation (Van Niekerk & Turpie 2010).

5) Scope of Study

This study follows the latest method for estuaries (Version 3 – DWA 2012).

ANNEXURE I:
MAP OF STUDY AREA