BREEDE-GOURITZ CATCHMENT MANAGEMENT AGENCY

Determination of the Ecological Water Requirements for the Klein Estuary

RDM Workshop Report

September 2015

ANCHOR environmental

1 INTRODUCTION

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). 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 National Water Act (Act No. 36 of 1998) (NWA) is founded on the principle that National Government has overall responsibility for and authority over water resource management for the benefit of the public without seriously affecting the functioning of the natural environment. In order to achieve this objective, Chapter 3 of the NWA provides for the protection of water resources, including ground water resources, through the determination and implementation of the Reserve for these resources. In support of this, CapeNature, with funding from the Breede-Gouritz Catchment Management Agency (BGCMA) appointed Anchor Environmental to determine the ecological reserve for the Klein estuary..

The project will be divided into a number of specific tasks, each with a defined deliverable in the form of an interim milestone report. Key deliverables from the study included the following:

- Site selection and delineation of resource units/integrated units of analysis;
- Outline of the socio-economic water use in the study area;
- Reference conditions, present ecological state and the ecological and socio-cultural importance and sensitivity of each resource unit;
- Recommended ecological categories of all the resource units;
- Set the ecological Reserve and describe the Ecological Resource Quality Objectives (RQO) or ecological specifications.
- Organise a technical workshop aimed at evaluating the identified scenarios and selecting the preferred scenario.
- Quantification of the ecological risks associated with each scenario; and
- Compile a basic monitoring programme with a list of priority indicators. It should also include a proposed implementation strategy defining the key resources.
- Compile the Reserve template for the resource as specified by the client and give input and review the final recommendations made in the templates.

This report provides a summary of the RDM workshop that was held as part of this study.

2 WORKSHOP AGENDA

08h30	Welcome	Barry Clark
08h45	Description of Present and Reference States	
	Hydrology	Barry Clark
	Hydrodynamics and sediment	Lara van Niekerk
	Water quality	Susan Taljaard, Lara van Niekerk
	Microalgae and Vegetation	Meredith Cowie
	Invertebrates	Aiden Biccard
	Fish	Steve Lamberth
	Birds	Jane Turpie
10h30	Tea/Coffee	All
11h00	Discussion on Present and Reference State	All
11h30	Determination of Estuarine Importance	All
12h00	Determination Recommended Ecological Category	Jane Turpie
12H30	Lunch	All
13h00	Description of Ecological Consequences of Alternative Scenarios	
	Hydrology	Barry Clark
	Hydrodynamics and sediment	Lara van Niekerk
	Water quality	Susan Taljaard, Lara van Niekerk
	Microalgae and Vegetation	Meredith Cowie
	Invertebrates	Aiden Biccard
	Fish	Steve Lamberth
	Birds	Jane Turpie
15h30	Tea/Coffee	All
15h45	Discussion and scoring of Alternative scenarios	All (led by Barry Clark)
16h15	Development of a mouth management plan for the Klein estuary	All (led by Barry Clark)
17h:00	Wrap-up and closure	Barry Clark

3 ATTENDANCE

Name	Position on project	Affiliation
Dr Barry Clark	Project leader	Anchor Environmental
Ms Lara van Niekerk	Hydrodynamics	CSIR
Dr Susan Taljaard	Water quality	CSIR
Ms M. Cowie	Microalgae & macrophytes	Nelson Mandela Metropolitan University
Mr A. Biccard	Invertebrates	Anchor Environmental
Dr S. Lamberth	Fish	Department Agriculture Forestry & Fisheries
Mr Corné Erasmus	Fish	Department Agriculture Forestry & Fisheries
Dr J. Turpie	Birds	Anchor Environmental
Pierre de Villiers	Client representative	Cape Nature

Apologies were received from the following persons:

Mr Jan van Staden BGCMA
Mr Patrick Coller BGCMA
Ms Barbara Weston DWS
Ms Wilna Kloppers DWS

4 WORKSHOP PRESENTATIONS

Copies of presentation delivered at the workshop are reproduced below.

KLEIN ESTUARY RDM STUDY

HYDROLOGY

Barry Clark & Stephen Mallory

17-18 May 2012

IWR Water Resources

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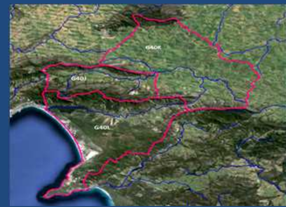
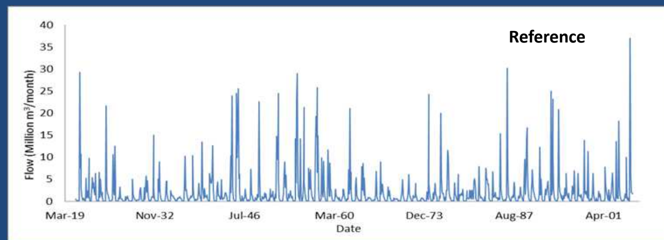
Background

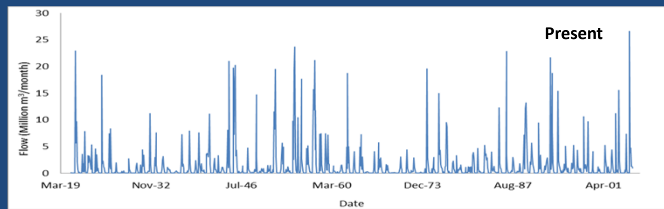


- Klein catchment:
  - Total area – 983 km²
  - 3 quaternary sub-catchments
  - well developed agricultural land
  - no hydrological monitoring stations within the catchment
- Water resources infrastructure
  - no major dams within the catchment
  - Small farm dams, largest = Tolbos Dam with a capacity of 238 million m³

Flow data from WR2005

Quaternary catchment	Natural Mean Annual Runoff (MAR) (million m³/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		





Flow scenarios

- DWA has no firm plans for increased utilisation of water in the Klein River catchment
- A number of hypothetical scenarios (n = 6) were constructed to examine likely impacts of further decreases (transfers out of the catchment) as well as some increases (restoration) in flow
- Restoration in flows was assumed to be achieved through removal of Invasive Alien plants (IAPs) and or reduction in water use for irrigation

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Flow scenarios

Scenario name	Description	MAR (x 10^6 m^3)	% Remain - ing
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

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Hydrological health: Present day

Variable	Score	Motivation	Conf
a.% 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
b.% Similarity in mean annual frequency of floods	87	Present day flood regime very similar to Reference as dams in the catchment are relatively small	L
Hydrology score	77		

- Present day flood regime is very similar to Reference as dams in the catchment are relatively small
- Occurrence of low and zero flow condition have increased dramatically under present day relative to reference conditions
- Under Reference conditions there were no months between 1920 and 2004 when zero flow was registered
- Under Present day condition, 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.

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Hydrological health: Scenarios

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Confidence
a. % similarity in MAR	77	98	93	75	67	59	53	Low
b. Mean annual frequency of floods	87	96	94	84	81	72	66	Low
Hydrology score	77	98	93	75	67	59	53	

- **MAR:** 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 events post-breaching.
- **Floods:** Scenario 1 shows a significant increase in flood volumes, while Scenario 2, 3 and 4 are somewhat similar to the present. However under Scenario 5 to 6 which incorporates a dam developments near the head of the estuary, there is a severe reduction in floods to the system.

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Klein Estuary
EWR study

Cape Town, 22 July 2015

Lara van Niekerk
Carla-Louise Ramjukadh
Years of collaboration: Piet Huizinga, Ed Lucas & Sue Matthews

CSIR
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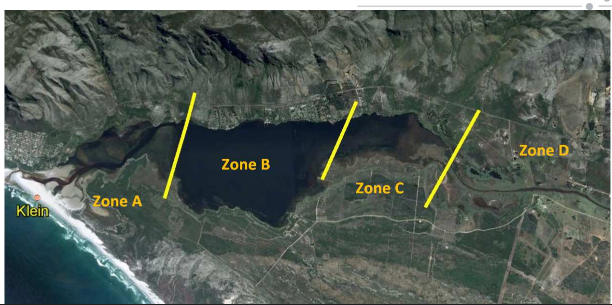
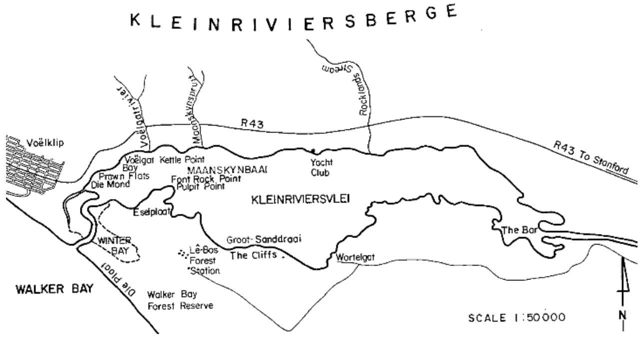
Estuary Boundary

Water Quality Station (since 2000)

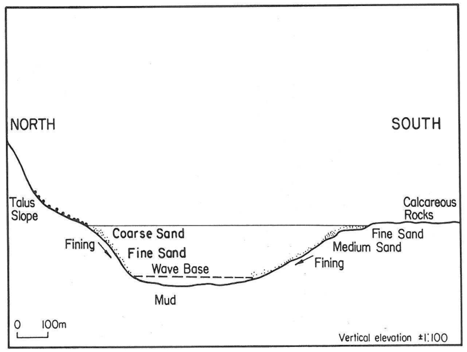
Sediment processes



	Zone A	Zone B	Zone C	Zone D
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



Sediment processes



Sediment processes

Sediment processes

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. In all zones locally been significantly changed, 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. They therefore directly encroach on parts of the supra-tidal habitat along the estuary, which also **reduces 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

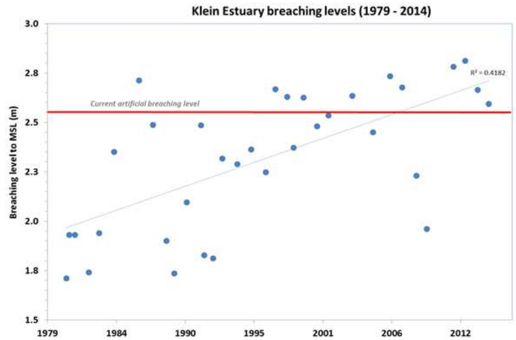
Sediment processes

Variable		Summary Of Change	Score	Conf
b	% similarity in area of intertidal sand- and mudflats	**Interatidal habitat in all zones of the estuary are still relatively similar to reference condition** i.t.o. sediment & morphologic characteristics, but all zones subjected to anthropogenic actions and developments. **Agricultural activities in the catchment lead to increased land erosion and thus sediment yield (especially fines) to the estuary.** The 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 and causes 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) are still relatively similar to reference condition, but Zone A and C have been significantly changed,** with both zones being infilled and under lower water levels being mostly confined to channel areas at present.	85	L/M
d	% similarity in bathymetry	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				L

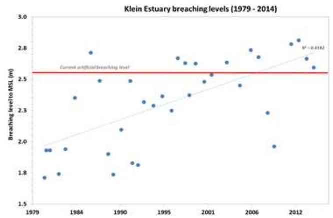
Water levels and artificial breaching

Past and present low lying developments that pressurise local authorities into artificial breaching at lower than natural levels.

A summary of breaching water level between 1979 & 2014

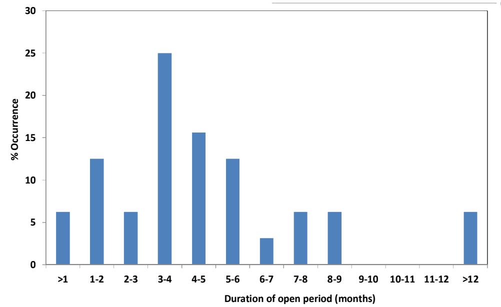


A summary of breaching water level between 1979 & 2014



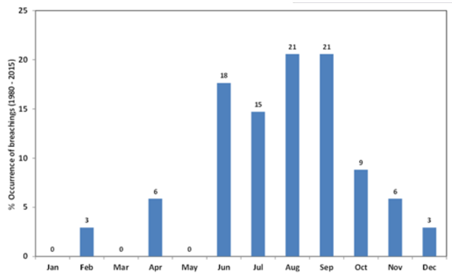
- Average breaching level is 2.32 m MSL (MIN: 1.71 m MSL, MAX: 2.81 m MSL)
- Average level at which the Klein Estuary mouth closes is 0.6 m MSL.
- Very weak correlation between "breaching water level" and "days open after breaching" Number of other factors also plays a role in maintaining an prolonged open mouth state, e.g mouth position & occurrence of high waves (coastal storm)

Duration of open mouth condition



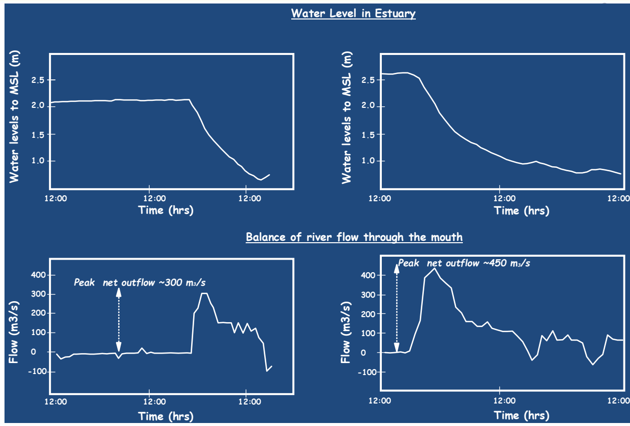
- Remain open between 3 and 4 months after a breaching, with a minimum period of 18 days and a maximum open period of 12.5 months.

Duration of open mouth condition

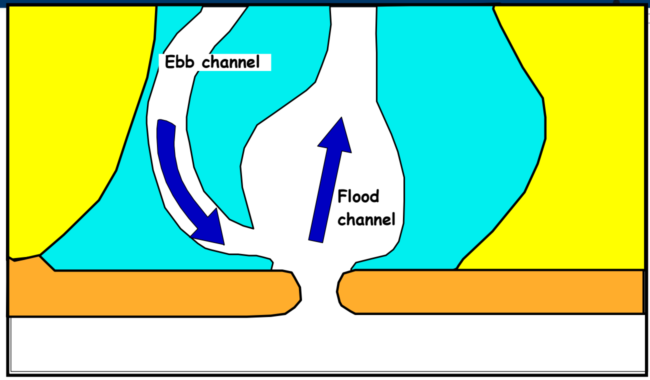


- The highest frequency of breaching occurs between June and September, with a peak towards early spring.
- The estuary remains closed for about 7 months of the year. With the longest period of closure, 25 months, associated with the 2010/11 drought. In addition the estuary also remained closed for more than a year in 1990/91 and 2003/05.

Increase in outflow when water level is higher at breaching

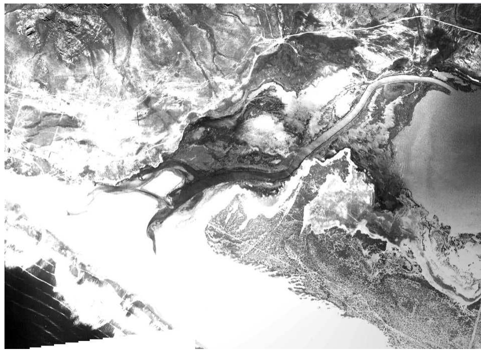


Role of ebb & Flood channels



Typical configuration of ebb and flood tidal channels at an inlet

Historical Imagery



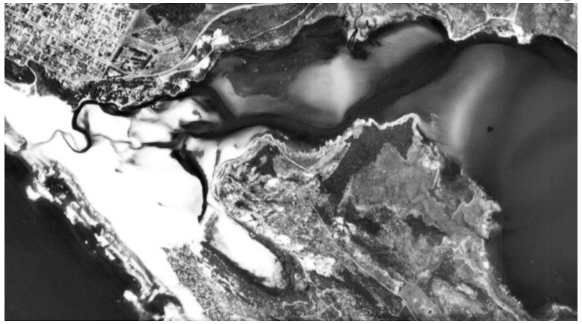
1938

Historical Imagery

1961

Historical Imagery

1973



1989

Historical Imagery

Historical Imagery

1998

Historical Imagery

1999

2001 (was open 11 months)

Photo courtesy of Ed Lucas

Historical Imagery

2011

Historical Imagery

13 November 2012

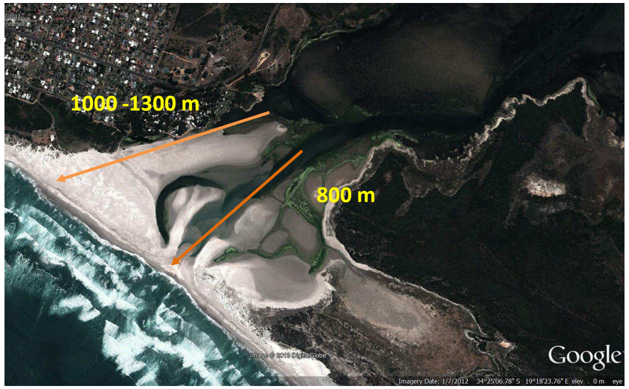
Photo courtesy of Giorgio Lombardi

3 December 2012.

Mouth closed by 8 December.

Photo courtesy of John Martin

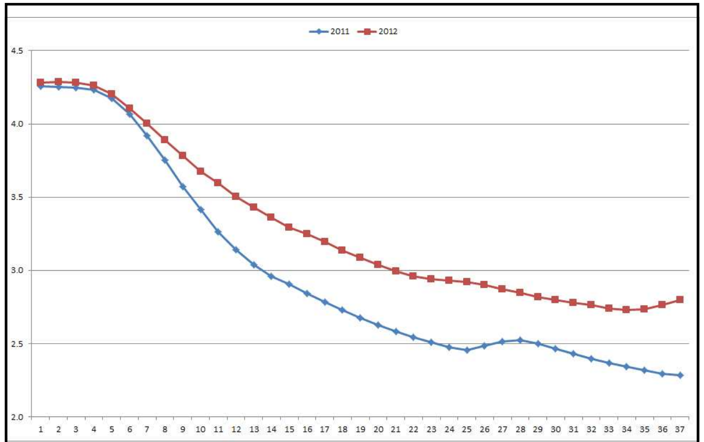
Shortest distance to sea



14 November – first spring high tide with westerly winds after end of rains brings masses of sand into lower reaches.

29 November

Outflow at low tide only ankle deep



Initial drop in water level after breaching reveals draining rate slower in 2012

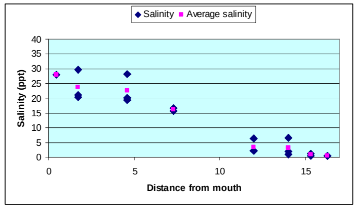
Observed Salinity

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

Salinity

In 2011, salinity was >15 throughout vlei within 2 weeks of breach.

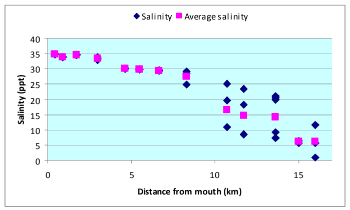
27 September 2011– 2 weeks after breach



At 6 weeks, salinity was >25 throughout vlei and seawater had pushed up into the river section of the estuary.

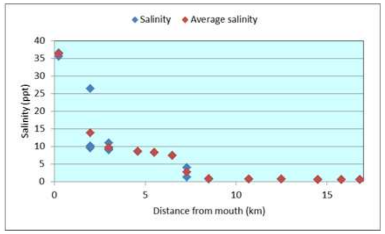
By the end of February, average salinity at Stanford was 22 ppt.

24-25 October 2011 – 6 weeks after breach



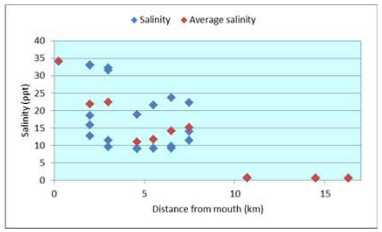
28 – 29 August 2012 – 2 weeks after opening

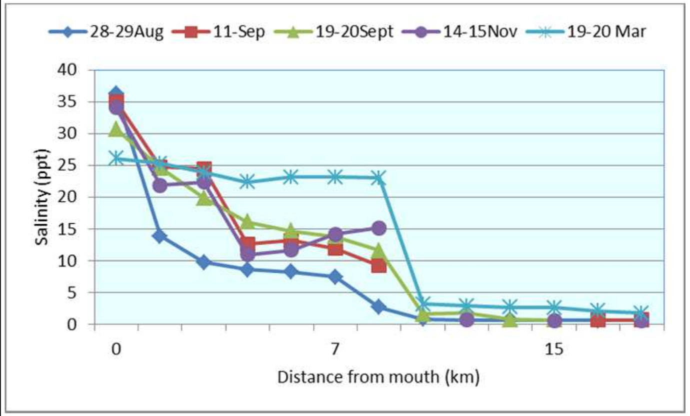
In 2012, average salinity was < 10 ppt in vlei 2 weeks after breach, apart from mouth and Elf Point.



14-15 November 2012 (spring high)

By mid-November, still only thin layer (1m) of saline bottom water throughout vlei, with 9ppt above it, except in mouth area up to Maanskynbaai. River fresh.





Average salinity

Abiotic States

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Abiotic States

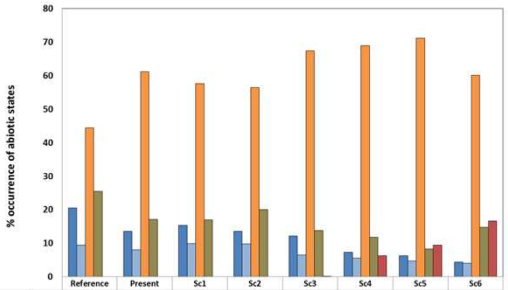
State	Name	Description
State 1	Open, marine	The mouth of the estuary is open, with the system under tidal conditions. Zone A to C is greater than 30, while Zone D is 20.
State 2	Open, gradient	The mouth of the estuary is open, with the system under tidal conditions. Zone A to B is greater than 30, while Zone C and D is about 25 and 10 respectively.
State 3	Closed, marine	The mouth of the estuary is closed, with the system at water levels below 1.6 m MSL. Zone A to C is greater than 30, while Zone D is 25.
State 4	Closed, brackish	The mouth of the estuary is closed, with the system at water levels greater than 1.6 m MSL. Zone A to C is 15 - 20, while Zone D is 10-15.
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 is hyper saline, 40 to 75. (This is a state that does not occur under the reference or present conditions.)

Abiotic States

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 / Strat-ified	Well mixed / Well mixed / Well mixed / Strat-ified	Well mixed / Well mixed / Well mixed / Well mixed	Well mixed / Well mixed / Strati-fied / Highly Strati-fied	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	Not occurring under reference, present, Sc 1 and 2; Sc 3 and 4: <45 / <45 / <45 / 35; Sc 5: 45-50 / 45-50 / 45-50 / 40; Sc 6: >60 / >60 / >60 / 50

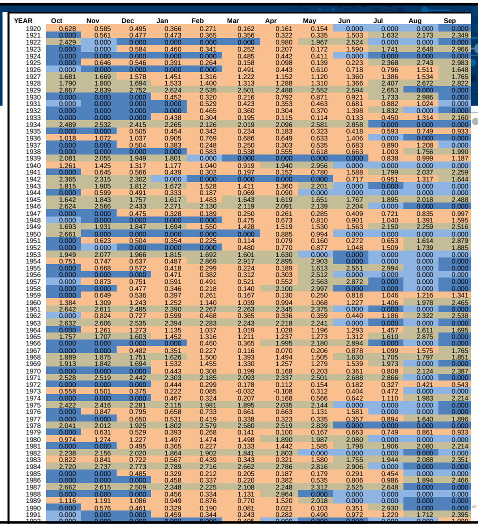
***ΔS = difference between the salinity of the surface and bottom water*

Future scenarios

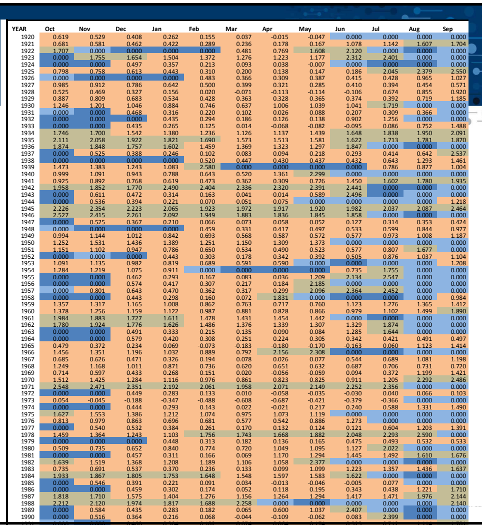


	Reference	Present	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6
State 1: Open, marine	21	14	15	14	12	7	6	4
State 2: Open, gradient	9	8	10	10	6	6	5	4
State 3: Closed, marine	45	61	58	56	67	69	71	60
State 4: Closed, brackish	25	17	17	20	14	12	8	15
State 5: Closed, hypersaline	0	0	0	0	0	6	10	17

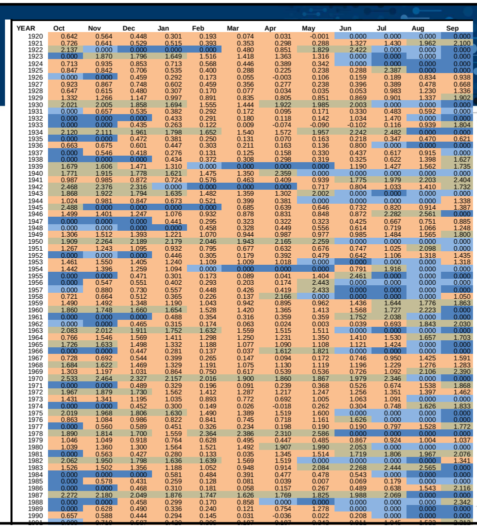
Reference

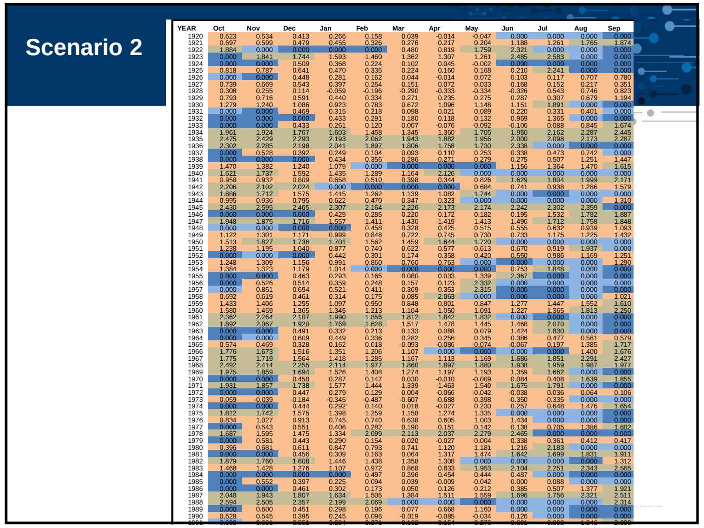


Present



Scenario 1

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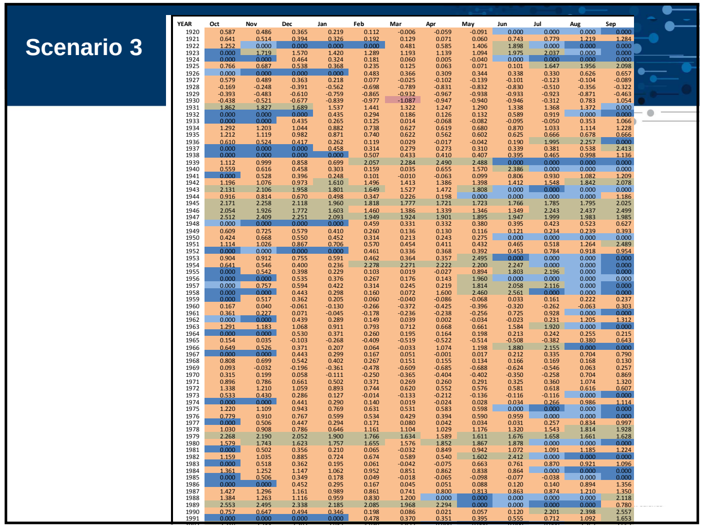
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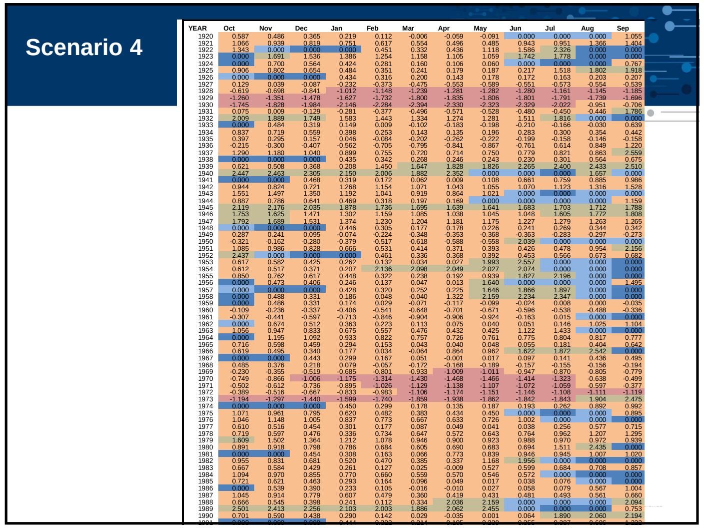
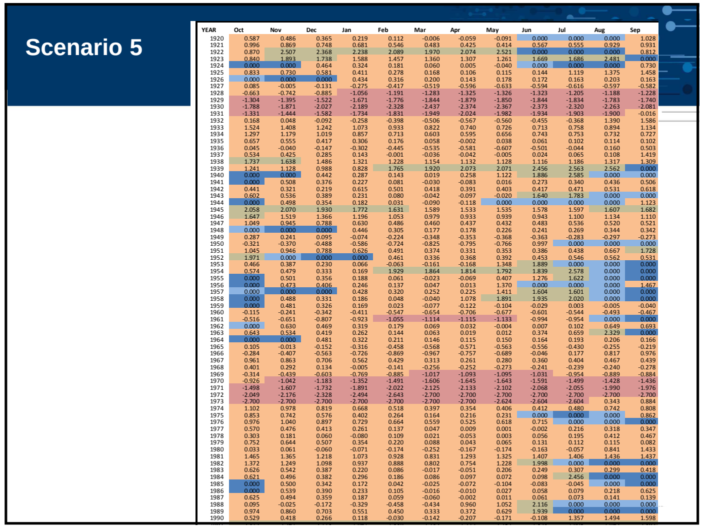

Scenario 4


Scenario 5

Scenario 6

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

Sediment Processes

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.

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**

Hydrodynamics

Parameter	Summary of changes
a. Mouth condition & abiotic states	% open mouth conditions under the various scenarios: Ref 30, Pres 22, Sc1 25, Sc2 23, Sc3 19, Sc4 13, Sc5 11, Sc6 8
b. Stratification	Estimated average salinity difference between surface and bottom salinity in water column: Zone A: Ref 0, Pres 0, Sc1 0, Sc2 0, Sc3 0, Sc4 0, Sc5 0, Sc6 0 Zone B: Ref 0, Pres 0, Sc1 0, Sc2 0, Sc3 0, Sc4 0, Sc5 0, Sc6 0 Zone C: Ref 3, Pres 2, Sc1 2, Sc2 2, Sc3 1, Sc4 1, Sc5 1, Sc6 1 Zone D: Ref 7, Pres 5, Sc1 5, Sc2 6, Sc3 4, Sc4 3, Sc5 2, Sc6 4
c. Water retention time	Not assessed
d. Water level	Estimated average change in water level from Reference: Present -0.10, Sc 1 -0.05, Sc 2 0.05, Sc 3 -0.01, Sc 4 -0.12, Sc 5 -0.15, Sc 6 -0.20

Mouth State

Parameter	Summary of changes
a. Mouth condition & abiotic states	% open mouth conditions under the various scenarios: Ref 30, Pres 22, Sc1 25, Sc2 23, Sc3 19, Sc4 13, Sc5 11, Sc6 8
b. Stratification	Estimated average salinity difference between surface and bottom salinity in water column: Zone A: Ref 0, Pres 0, Sc1 0, Sc2 0, Sc3 0, Sc4 0, Sc5 0, Sc6 0 Zone B: Ref 0, Pres 0, Sc1 0, Sc2 0, Sc3 0, Sc4 0, Sc5 0, Sc6 0 Zone C: Ref 3, Pres 2, Sc1 2, Sc2 2, Sc3 1, Sc4 1, Sc5 1, Sc6 1 Zone D: Ref 7, Pres 5, Sc1 5, Sc2 6, Sc3 4, Sc4 3, Sc5 2, Sc6 4
c. Water retention time	Not assessed
d. Water level	Estimated average change in water level from Reference: Present -0.10, Sc 1 -0.05, Sc 2 0.05, Sc 3 -0.01, Sc 4 -0.12, Sc 5 -0.15, Sc 6 -0.20

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	-							
d. Water level	97	96	97	97	93	89	79	L
Hydrodynamics score	**72**	**84**	**78**	**62**	**43**	**37**	**28**	**L**

Salinity

Zones	Volume weight	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

Note: Average salinity. It does not reflect impact of hyper salinity

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)	L-M

Mouth position….

- Water level as high as possible (>2.6 m MSL)
- Breach any time. Don't pinch in like Bot Estuary.
- 2012 mouth position:
  - System has to work very hard to remain open as it adds an extra 200 - 400 m of constricted mouth leading to increase sedimentation and loss of scouring power at a breaching.
  - Too far west - prevents the ebb channels from forming resulting in premature closure
  - Prevents good tidal flushing resulting in low salinities - Klein looks more like Bot
- Optimum position for estuary mouth is near the middle - not to far west or east.
- Estimated 25 % reduction in MAR already leading to loss of scouring potential (especially if combined with artificial breach).
- Breach at same level but more towards middle linking up with old channels
- Look into re-establishing the dune at the mouth to protect car park.

Klein Estuary

Other Water Quality

our future through science

Water Quality Parameters

- Dissolved inorganic nutrients: DIN ($NO_xN + NH_4$-N) and DIP
- Dissolved oxygen
- Suspended solids
- Toxic substances

Zones in Estuary

Description of Scenarios

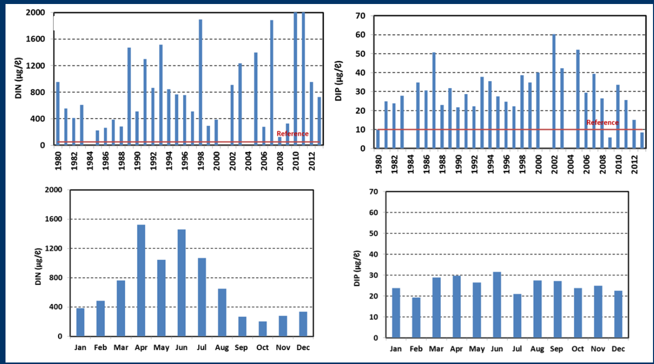
Scenario	Description	MAR (x 10^6 m^3)
Natural	Reference condition	53.41
Present	Present day	40.88
1	+ 20% of Present (remove all IAPs, reduce irrigation by 46%)	47.54
2	+ 10% of Present (remove all IAPs)	44.89
3	- 12% of Present (i.e. 33% reduction from Natural)	36.05
4	- 21% of Present (i.e. 40% reduction from Natural)	32.22
5	- 28% of Present (i.e. 49% reduction from Natural)	27.50
6	- 41% of Present (i.e. 55% reduction from Natural)	24.08

Component of Stanford WWTW inflow under Present and all Future Scenarios:

- 500 m^3/day (0.006 m^3/s)

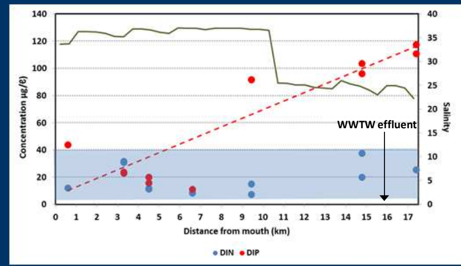
Inorganic Nutrients (River)

DIN ($NO_xN + NH_4$-N) **DIP**



DWS Station: G6H4

Inorganic nutrients (Estuary)



May 2012 (unpublished data, Overberg Municipality)

- DIN depleted (<50 µg/ℓ)
- DIP increased moving upstream into less saline water
- Mostly "old" seawater (salinity in lower estuary 35) introduced during preceding open state (Jan 2012)
- DIN limiting nutrient already taken up by PP ?

Inorganic nutrients (States)

Limited data, therefore calculated nutrient distribution in estuary for various states:

- Assumed present concentrations in inflow (WWTW DWS G40-1000010167):

PARAMETER	WWTW	River (summer)	River (spring)	River (winter)
DIN (µg/ℓ)	18000	400	800	1500
DIP (µg/ℓ)	6000	20	25	30

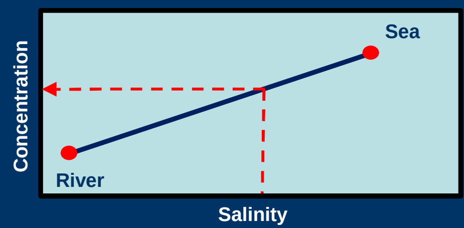
- Present Inflow for each state:

$$(Vol_{WWTW} * Conc_{WWTW}) + (Vol_{RIVER} * Conc_{RIVER}) / Vol_{TOT}$$

- Sea and Reference Inflow concentrations (from literature)

Inorganic nutrients (States)

- Assumed linear relationship between Nutrient concentrations and Salinity



- Calculated Nutrient concentration in various zones in estuary from salinity

Inorganic nutrients (States)

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

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	100	100	100	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

Inorganic nutrients (Scores)

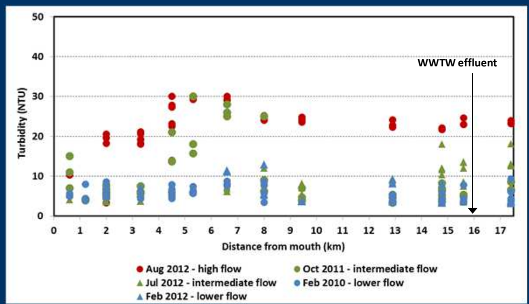
Zones in Estuary	Volume weighting for Zone	Estimated DIN concentration (µg/ℓ) based on distribution of abiotic states							
		Reference	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6
A (lower)	0.25	61	198	148	215	180	169	146	188
B	0.45	50	191	141	208	174	166	143	186
C	0.20	50	211	166	233	189	181	155	196
D (upper)	0.10	63	684	616	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	18	19	19	19	20	20
B	0.45	10	18	16	18	18	19	19	19
C	0.20	10	19	17	19	19	19	19	20
D (upper)	0.10	10	29	26	29	29	33	56	109
			56	63	55	57	57	59	51

Marked increase in nutrient input from anthropogenic sources (e.g. agriculture and WWTW effluent) present and future scenarios

Confidence: M/L

Turbidity



DAFF /CSIR (unpublished data):

- **High flows tended to be higher (~20-30 NTU)**
- **Intermediate flows, turbidity varied (<10 to 30 NTU)**
- **Lower flows periods system remain relatively clear (<10 NTU)**

Turbidity (States)

Limited data, therefore calculated turbidity distribution form river inflow and salinity:

- **Assumed present turbidity in inflow:**

PARAMETER	WWTW	River (summer)	River (spring)	River (winter)
Turbidity (NTU)	20	10	20	30

- **Present inflow for each state:**

$$(Vol_{WWTW}*Conc_{WWTW})+(Vol_{RIVER}*Conc_{RIVER})/Vol_{TOT}$$

- **Sea and reference concentrations (from literature)**
- **Assumed linear relationship between turbidity and Salinity**
- **Calculated Turbidity in various zone in estuary from Salinity**

Turbidity (States)

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

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

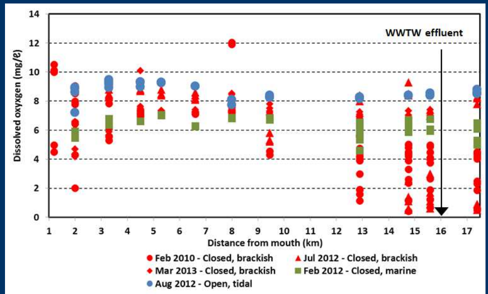
Turbidity (Scores)

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	10	12	11	11	11	12
B	0.45	10	12	10	12	11	11	11	12
C	0.20	10	12	10	12	11	11	11	12
D (upper)	0.10	10	12	10	12	11	11	11	12
			91	88	91	90	90	90	90

No marked increase in turbidity, only slight increase compared with reference due to increased suspended solid loading from catchment (high flows) and WWTW (low flows)

Confidence: M/L

Dissolved oxygen



DAFF /CSIR (unpublished data):

- Open, tidal state systems well oxygenated (>6 mg/ℓ) (e.g. Aug 2012)
- Closed periods when system is brackish (i.e. long residence times with significant amounts of enriched freshwater still entering , DO drop to 4 mg/ℓ, even below 2 mg/ℓ, especially upper estuary
- Closed periods when little freshwater enters , DO levels remain stress (mostly below 6 mg/l), but not as severe as in brackish closed states

Dissolved oxygen (States)

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	6	5	2				
Scenario 1	8	6	6	4	8	6	6	6	5	6	5	4	4	6	5	2				
Scenario 2	8	6	6	4	8	6	6	6	5	6	5	4	4	6	5	2				
Scenario 3	8	6	6	4	8	6	6	6	5	6	5	4	4	6	5	2	5	6	5	4
Scenario 4	8	6	6	4	8	6	6	6	5	6	5	4	4	6	5	2	5	6	5	4
Scenario 5	8	6	6	4	8	6	6	6	5	6	5	4	4	6	5	2	5	6	5	4
Scenario 6	8	6	6	4	8	6	6	6	5	6	5	4	4	6	5	2	5	6	5	4

Dissolved oxygen (Scores)

Zones in Estuary	Volume weighting for Zone	Estimated DISSOLVED OXYGEN concentration (mg/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	7	5	5	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	4
			92	99	91	94	94	96	93

Increase in organic loading and nutrient input (causing eutrophication) from anthropogenic sources (e.g. agriculture and WWTW effluent) reduced levels, especially in the upper reaches

Confidence: M/L

Toxic Substances

⇧ Agriculture in catchment (herbicides and pesticides) and urban development along banks (metals and hydrocarbons) introduced some toxic substances into the estuary

Present and all Scenarios: 80

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Klein RDM Microalgae Present

Janine Adams and Meredith Cowie

Present assessment

- Data availability
  - De Decker (1989)
- Scott et al. (1952, in De Decker 1989) refer to discoloration of the sand in parts of the estuary as a result of a large number of benthic microalgae. Grindley (1957, 1965) have listed the following for diatoms, *Triceratium, Skeletonema, Coscinodiscus, Rhizosolenia, Nitzschia*, *Bacillaria* and *Chaetoceros* (cited in De Decker 1989).
- Some chlorophyll data from 2012 (CSIR) shows that phytoplankton blooms (> 20 ug/l) do occur.
  - Abiotic drivers (Lara & Susan) and botanical understanding

Present area

Microalgal 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 (chlorophyll a > 20 ug/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.

Abiotic drivers

	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

Abiotic states identified

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 microalgal biomass is expected. Phytoplankton blooms could occur in the water column.
State 4	Closed, brackish	High subtidal benthic microalgal biomass in water less than 1m depth. Phytoplankton blooms could occur.
State 5	Closed, hypersaline	Salt tolerant phytoplankton groups such as the cyanobacteria (blue/green) algae could bloom.

Change from reference

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

Present microalgae score

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

(cont.)

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 microalgal communities.	70	M
Microalgae health score min (a to c)		**65**	**M**
% of impact non-flow related impacts		50	
Adjusted score			

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Klein RDM Microalgae Scenarios

Janine Adams and
Meredith Cowie

Responses of microalgae to 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 microalgal growth.

(cont.)

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, microalgal 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.

Scenario scores

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**	

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Klein RDM Macrophytes Present

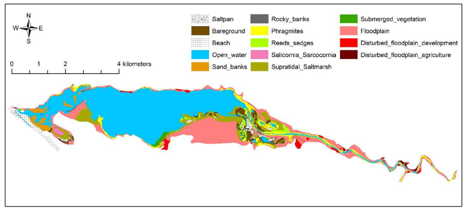
Janine Adams and
Meredith Cowie

Present assessment

- Data availability
  - Aerial photos (1938, 1980 CSIR)
  - Google Earth 2009
  - De Decker (1989)
  - Bornman 2006 (Turpie and Clark 2007)
  - 5 m contour
  - Veldkornet (2013)
  - Abiotic drivers (Lara & Susan) and botanical understanding

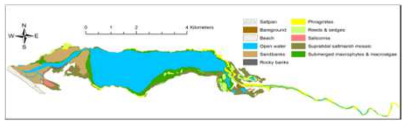
Present assessment

- Habitats (7 of 9)
  1. Salt marsh (intertidal and supratidal)
  2. Submerged macrophytes
  3. Reeds and sedges
  4. Macroalgae
  5. Open water
  6. Sand and mudflats



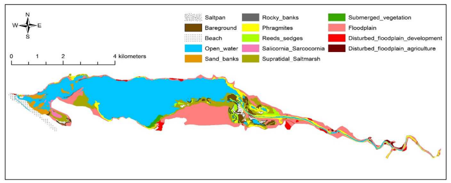
Macrophyte distribution

De Decker (1989)



Bornman (2006)

2014



Present area

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. Included in this habitat was saltpans located in the middle reaches of the estuary.	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 in provided based on mapping from Bornman (2006).	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) 390 (mostly intact)

Anthropogenic influences

- artificial breaching
- bank stabilisation and destabilisation
- invasive aliens
- agricultural in catchment degradation
- boating activities
- low-lying developments

Abiotic states identified

State	Name	Responses
State 1	Open, marine	Persistent conditions would cause die-back of reeds and sedges in the middle reaches (salinity of 20 ppt 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 macroalgal 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.

Change from reference

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 need stable closed mouth conditions and high water level
⇧ agriculture, disturbance & invasive plants	⇩ Macrophyte habitats and disturbance of floodplain habitat
⇧ nutrient enrichment	⇧ Macroalgal blooms
TOTAL CHANGE	⇩ Reed & sedge ⇩ Salt marsh ⇩ Submerged macrophytes ⇧macroalgae

Present state Score - abundance

	Reference	Present	
Salt marsh	220	170	
Reeds & sedges	180	127	
Submerged	190	139	
Natural habitat (now invasive)	10	0	degraded
Floodplain	280	280	
Floodplain developed	35	0	degraded
Floodplain disturbed	110	0	
SUM	1025	716	

70 %

% similarity Score

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

Present macrophyte score

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 macroalgal 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		**70**	
% of impact non-flow related		20	
Adjusted score			

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Klein RDM Macrophytes Scenarios

Janine Adams and Meredith Cowie

Responses of macrophytes to scenarios

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 macroalgal 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 macroalgal blooms due to an increase in the duration of mouth closure and the continued high nutrient input. ⇩ reeds & sedges, salt marsh ⇩ submerged macrophytes ⇧macroalgae

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(cont.)

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, macroalgal 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 conditons) 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

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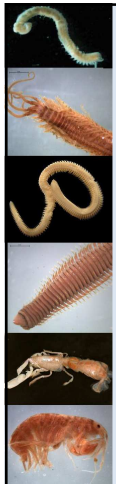
Scenario scores

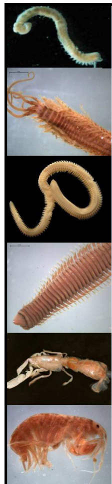
VARIABLE	SCENARIO							
	PRESENT	1	2	3	4	5	6	CONF
a. Species richness	80	85	82	70	60	50	40	M
b Abundance	70	80	75	60	50	40	30	M
c. Community composition	81	90	85	70	60	50	40	M
Macrophyte score min (a to c)	70	80	75	60	50	40	30	

Nelson Mandela Metropolitan University for tomorrow



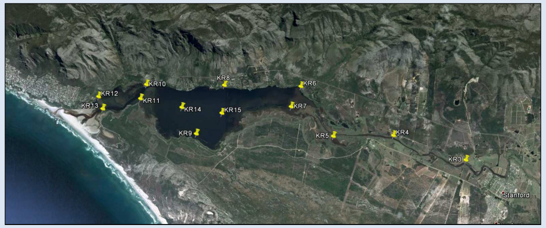
Klein Rivier Estuary RDM Study Invertebrates

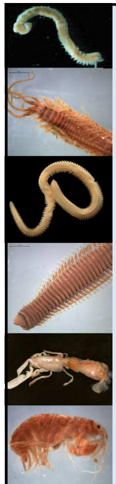
Aiden Biccard



Available data

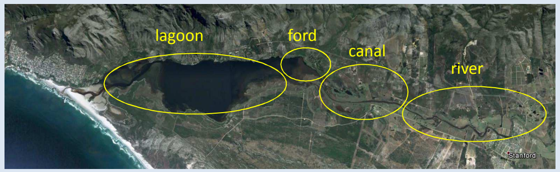
- Scott *et al.* (1952)
- Qualitative data collected during several field trips over three years (1947 – 1949) at sites figured below
  - Bucket and spade on exposed sand/mud banks
  - Below the water line, D-net dredge and hand nets

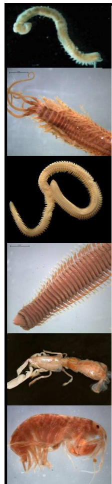




Reference condition

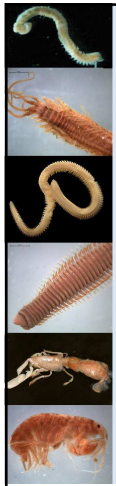
- 45 soft-bottom invertebrate macrofauna species (Scott et al., 1952).
- 25 "hard-substratum" species (mostly marine rocky shore taxa restricted to rocky outcrops near the lower reaches) – temporary establishment, unable to withstand freshwater flooding during winter.
- 10 species which inhabit the water column
- Sand prawn: "occurred frequently in very large numbers"…. "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".





Classification

#	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



Current study – field work

- Soft bottom benthic macrofauna sampled in March 2015 (mouth closed) at same sampling sites as Scott *et al.* (1952).
- Collected with van Veen Grab (bite size 200cm^2), washed through 1mm mesh.
- Macrofauna extracted, fixed and preserved in ethanol.
- Identified to species level.
- Sediment samples collected for grain size and TOC

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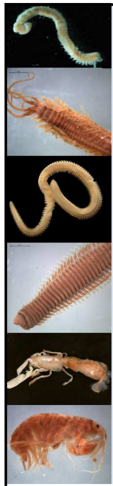

Results

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

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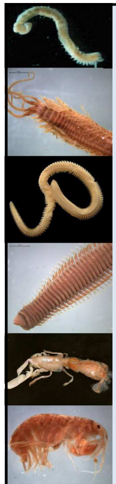

Results

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
Cyathura 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

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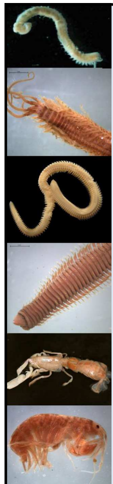
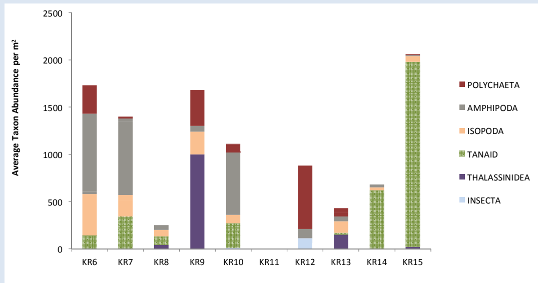


Results



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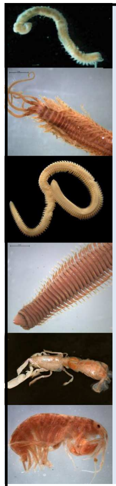
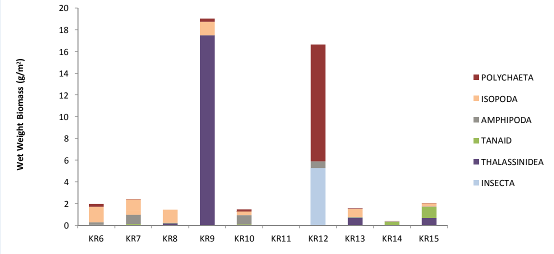


Results



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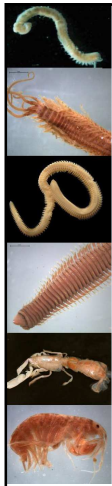

To sum up…

- A total of 45 soft-bottom invertebrate macrofauna species were recorded during the Scott et al. (1952) study versus 14 in the March 2015 study.
- Results from 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.
- Different sampling techniques were used.
- Reduction in alpha diversity can be attributed to differences in sampling effort and methodology mentioned above.
- The most significant change in the soft-bottom invertebrate macrofaunal community structure from the reference condition = decline in both abundance and biomass of *C. kraussi* and *A. loveni*

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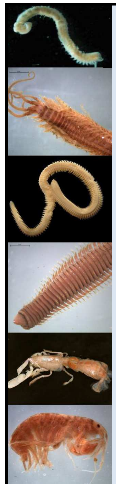

To sum up…

- Most likely a combination of anthropogenic impacts, change in flow and natural variability.
- 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 confidence around this conclusion would be low.
- Recommended that hard substrata and the water column are sampled in future surveys.

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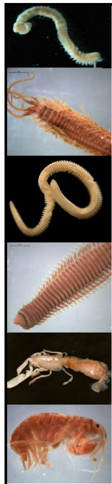

Health scores

Variable	Change from natural	Score	Confidence
1. Species richness	Some loss in diversity (sensitive species such as *A. loveni*) from anthropogenic impact(s) and physical change in the system. 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	H
2. Abundance	Absence of large species (sand prawn and bloodworm) – some only present as recruits. Small taxa (amphipods, isopds and tanaids) resident in weed beds and remain abundant. 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.	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		70	L
Degree to which deviation from natural is due to non-flow related impacts		<10%	L
Adjusted score			

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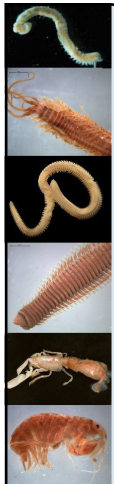
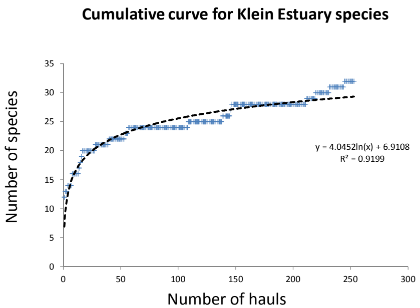


Health scores - scenarios

Scenario name	Description	MAR (x 10^6 m^3)	% remaining	Invertebrate health score
Natural	Reference condition	53.41		
Present	Present day	40.88	76.5	70
Scenario 1	+ 20% of Present (remove all IAPs, reduce irrigation by 46%)	52.08	97.5	95
Scenario 2	+ 10% of Present (remove all IAPs)	49.43	92.6	90
Scenario 3	- 12% of Present (i.e. 33% reduction)	40.00	74.9	55
Scenario 4	- 21% of Present (i.e. 40% reduction)	36.17	67.7	50
Scenario 5	- 28% of Present (i.e. 49% reduction)	31.45	58.9	40
Scenario 6	- 41% of Present (i.e. 55% reduction)	28.03	52.5	<30

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**



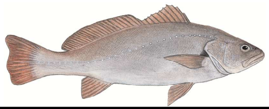
Klein Estuary fish assemblage

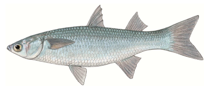
Ia	Resident breeders	2
Ib	Marine & estuarine breeders	8
IIa	Obligate dependents	9
IIb	Partial dependents	5
IIc	Marine opportunists	5
III	Marine vagrants	11
IV	Freshwater	5
Va	Catadromous	8
Vb	Facultative catadromous	(2)

	Spring	Summer	Autumn	Winter	Total	% catch	% occurrence
Psammogobius knysnaensis	109.61	62.27	55.23	40.89	70.72	8.192	71.75
Atherina breviceps	695.29	334.09	323.58	143.74	401.67	45.664	63.57
Liza richardsonii	108.67	153.24	79.21	31.67	90.27	10.456	55.39
Syngnathus temminckii	5.99	6.37	9.88	3.32	6.17	0.715	44.61
Gilchristella aestuaria	192.08	395.69	388.40	85.93	244.06	28.167	43.49
Caffrogobius spp.	50.28	14.41	11.88	7.00	23.70	2.725	42.75
Clinus spatulatus	18.25	39.14	6.58	4.26	15.99	1.853	36.80
Solea turbynei	0.19	1.37	1.37	0.06	0.63	0.073	12.27
Tilapia sparrmanii	0.21	3.75	0.56	0.36	1.00	0.115	8.55
Hyporhamphus capensis	0.30	1.94	1.00	0.22	0.74	0.086	7.43
Heteromycterus capensis	0.31	1.45	0.21	0.68	0.62	0.066	7.43
Mugillidae	1.00	44.49	0.16		8.80	1.019	7.06
Myxus capensis	6.46	0.31	1.32	0.04	2.49	0.288	6.69
Mugil cephalus	0.31	1.02	0.63	0.11	0.46	0.053	5.95
Rhabdosargus globiceps	0.01	4.20	4.09	3.19	2.52	0.292	4.83
Oreochromis mossambicus	0.01	2.73	3.75	0.03	1.32	0.153	3.72
Sandelia capensis	0.07	0.37	0.14		0.12	0.014	2.97
Liza dumerili	0.42	0.12	0.39		0.24	0.028	2.60
Pomatomus saltatrix		0.04	0.05		0.02	0.002	1.86
Lichia amia		0.06	0.18		0.05	0.006	1.49
Diplodus capensis		0.06	0.04	0.03	0.03	0.003	1.49
Monodactylus falciformis		0.06	0.04	0.03	0.03	0.003	1.49
Micropterus salmoides		0.06	0.02		0.01	0.002	1.49
Lithognathus lithognathus	0.16	0.08			0.07	0.008	1.12
Lepomis macrochirus	0.02			0.01	0.01	0.001	1.12
Liza tricuspidens	0.02				0.01	0.001	0.74
Rhabdosargus holubi	0.22				0.07	0.009	0.37
Sarpa salpa	0.03				0.01	0.001	0.37
Micropterus dolomieu	0.02				0.01	0.001	0.37
Amblyrhynchotes honckenii	0.01				0.00	0.000	0.37
Pomadasys olivaceum	0.01				0.00	0.000	0.37
Total per haul	**1190**	**1067**	**889**	**322**	**872**		

Klein Estuary fish instream distribution

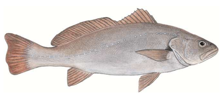
	Dependence category	S‰	>30	20-30	10-20	<10
Ia	Resident breeders		49	21	6	24
Ib	Marine & estuarine breeders		36	35	26	3
IIa	Obligate dependents		2	6	1	91
IIb	Partial dependents		73	7	15	4
IIc	Marine opportunists		62	14	13	10
III	Marine vagrants					
IV	Freshwater		5	45	9	41
V	Catadromous					100

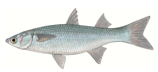




Klein Estuary fish % catch per salinity range

	Dependence category	S‰	>30	20-30	10-20	<10	Total
Ia	Resident breeders		42	28	12	42	37
Ib	Marine & estuarine breeders		44	67	80	44	53
IIa	Obligate dependents		<1	<1	0	<1	<1
IIb	Partial dependents		<1	<1	0	<1	<1
IIc	Marine opportunists		14	5	7	14	9
III	Marine vagrants		<1	<1	0	<1	<1
IV	Freshwater		<1	1	0	<1	<1
V	Catadromous						



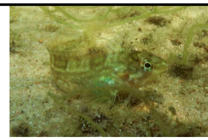


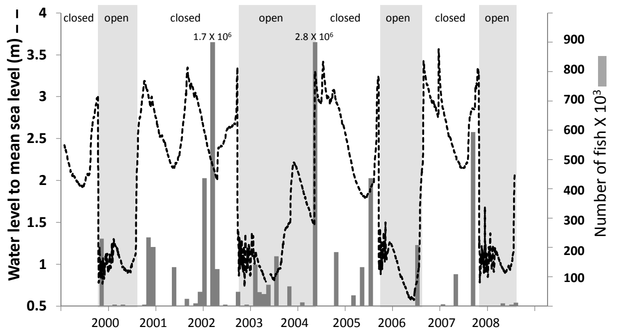
Fish kills

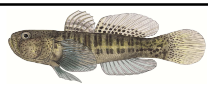
Connectivity - flood plumes

Lamont 2014

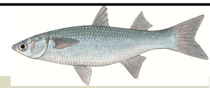
Clinus spatulatus population versus water level



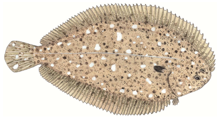




Scenario	**Summary of changes**
Scenario 1	Slight⇧ mouth opening, ⇧recruitment. ⇧ microalgal biomass, ⇩dissolved oxygen (mg/l), ⇧night-time stress. ⇩ *C. spatulatus, S. temminckii, Caffrogobius* macrophyte habitat , ⇩benthic microalgae, ⇩Mugillidae
Scenario 2	Mouth closure⇧ similar to present, = recruitment 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



Variable	Change from natural	Score	Confidence
1. Species richness	51 species similar to reference, *C. spatulatus* persisted. Some estuarine-dependent species functionally absent, 6 alien species in Zone D. Marine species absent.	80	H
2. Abundance	*A. breviceps* and *G.aestuaria* = reference, ⇩⇩recruitment of estuarine-dependent marine species ⇩⇩ exploited.spp. *C. spatulatus* < population fluctuations Bot , In 15 years, 250 seine hauls, only 4 category III individuals. ⇧⇧ Freshwater invasives	60	H
3. Community composition	⇩⇩Piscivorous fish, some absent e.g. *A. japonicus*. Small estuary-resident fodder fish unchanged,⇧⇧gillnet poaching ⇩⇩adult marine opportunistic Mugillidae & detritivores. Introduced *O. mossambicus* herbivorous but territorial excluding indigenous species.	70	H
Fish score		60	H
% due to non-flow related impacts		50	M
Adjusted score			



Future 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	60	65	60	60	50	40	40	M

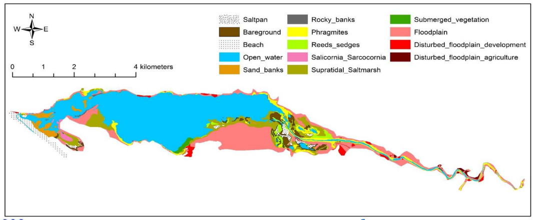
Klein Estuary RDM

Specialist study: Birds

Jane Turpie

Bird habitats

- Large system, diversity of habitats
  - high diversity of birds
- Black water system but high retention
  - Low water vis
  - Relatively productive
- Typically open and tidal over summer months
  - – low water levels + tidal = good for waders
- Typically closed and marine or brackish over winter
  - Higher water levels, lower salinities = good for waterfowl



Available data on waterbirds

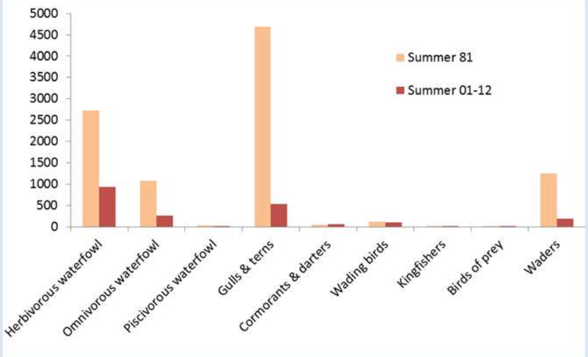
- First full count = Jan 1981
- Summer and winter CWAC counts 2001-12

Date	Type of count	Reference
January 1976	Waders	Summers et al. 1976
January 1981	Full	Underhill & Cooper 1984, Ryan et al. 1988
January 2001 -January 2012	Full	CWAC data

Diversity and abundance

- Total number of non-passerine waterbird species recorded
  - 67 species in total
  - 58 in summer
  - 51 in winter.
- Ave species recorded per count
  - 32 in summer
  - 26 in winter
- Numbers recorded
  - Jan 1981 – 9974
  - CWAC summer – 1498
  - CWAC winter - 1807

1981 vs present



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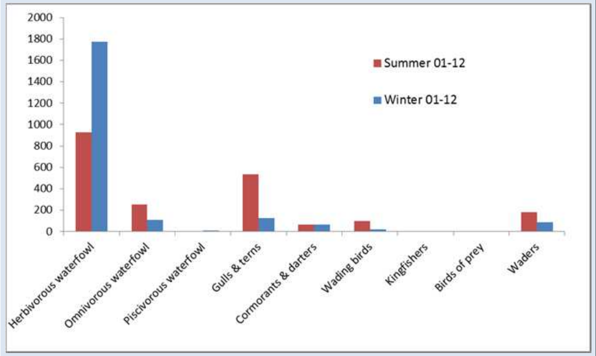
Composition
Summer vs. winter



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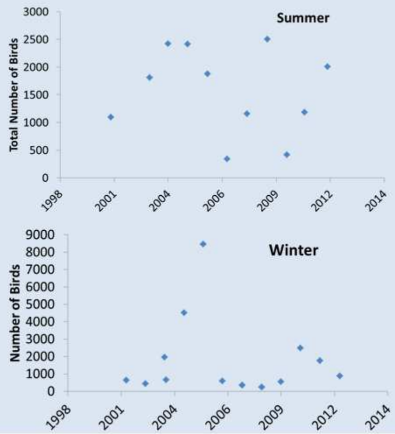
Overall numbers



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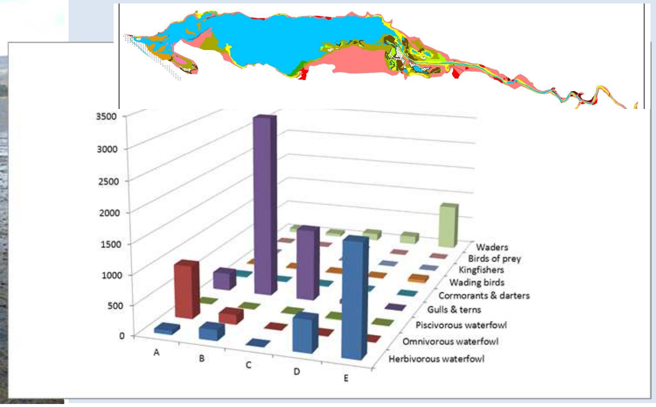
Distribution along estuary



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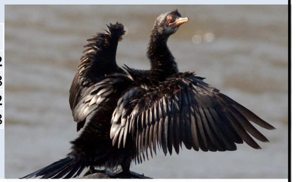
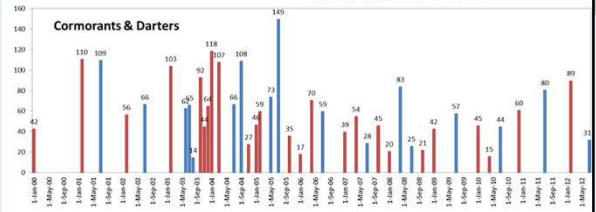
Cormorants & darters

Mean & max since 2000

	Mean	Max
Cormorant, White-breasted	**32**	**92**
Cormorant, Cape	5	18
Cormorant, Reed	**27**	**82**
Darter, African	3	8





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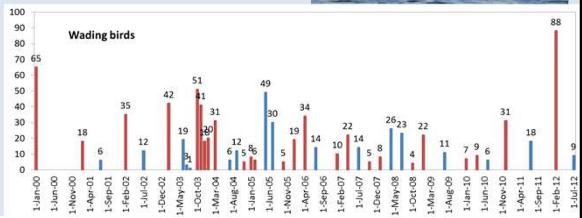
Wading birds

	Mean	Max
Heron, Grey	**10**	**31**
Heron, Goliath	1	1
Heron, Purple	1	2
Egret, Little	**9**	**62**
Egret, Yellow-billed	1	1
Egret, Cattle	9	20



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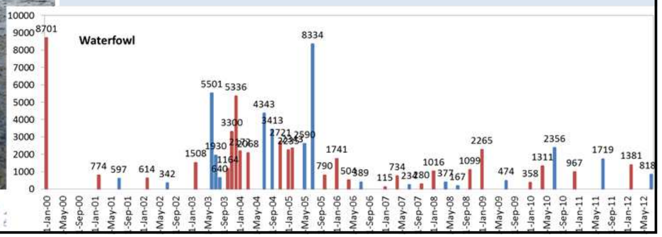
Waterfowl

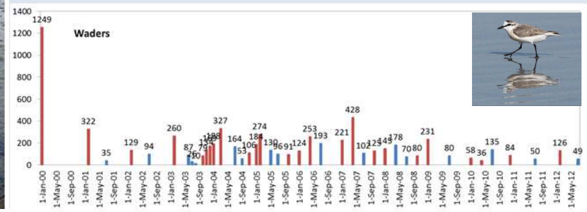
	Mean	Max
Goose, Egyptian	16	69
Moorhen, Common	3	6
Coot, Red-knobbed	**1290**	**7600**
Goose, Spur-winged	8	19
Shoveler, Cape	**60**	**222**
Duck, African Black	2	2
Duck, Yellow-billed	**113**	**465**
Teal, Red-billed	7	28
Teal, Cape	12	47
Duck, Maccoa	2	2
Duck, White-backed	2	2
Rail, African	1	1
Crake, Black	1	1
Grebe, Great Crested	6	16
Grebe, Black-necked	2	2
Grebe, Little	5	18



Waders

	Mean	Max
Plover, Common Ringed	12	29
Plover, Grey	17	45
Sandpiper, Curlew	**66**	**179**
Stint, Little	**37**	**78**
Sandpiper, Common	2	15
Greenshank, Common	12	36
Sandpiper, Wood	3	4
Godwit, Bar-tailed	2	2
Curlew, Eurasian	2	2
Whimbrel, Common	**18**	**58**
Wagtail, Cape	8	29

	Mean	Max
Oystercatcher, African Black	**30**	**78**
Turnstone, Ruddy	2	2
Sanderling, Sanderling	0	0
Plover, White-fronted	**31**	**158**
Plover, Kittlitz's	14	148
Plover, Three-banded	5	15
Lapwing, Blacksmith	10	26
Knot, Red	9	17
Ruff, Ruff	8	12
Sandpiper, Marsh	2	2
Avocet, Pied	0	0
Stilt, Black-winged	**17**	**55**
Thick-knee, Water	2	2



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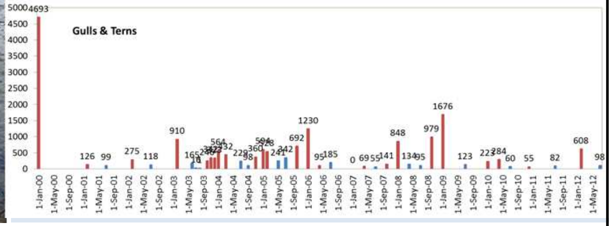
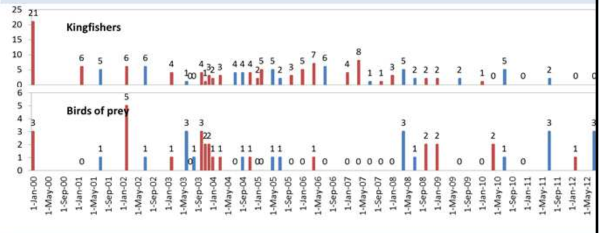
Gulls & terns

	Mean	Max
Gull, Kelp	**53**	**258**
Gull, Grey-headed	2	4
Gull, Hartlaub's	**81**	**286**
Tern, Caspian	6	26
Tern, Common	**307**	**1500**
Tern, Sandwich	29	106
Tern, Swift	26	144



Kingfishers, Birds of Prey

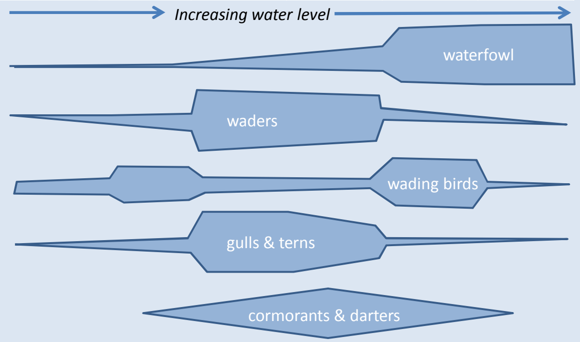
	Mean	Max
Pied Kingfisher	3	8
Giant Kingfisher	1	2
Malachite Kingfisher	1	1
African Fish-Eagle	1	3
African Marsh-Harrier	1	1
Osprey	1	3



Main drivers for avifauna

- Habitat availability:
  - Intertidal, shallow water, deep water, marginal vegetation, floodplain marshes, safe roosting areas, salinity
- Food availability:
  - Macrophytes, fish and invertebrate populations

State 5: Closed, hypersaline	State 3: Closed, marine	State 1: Open, marine	State 2: Open, gradient	State 4: Closed brackish	Freshwater dominated



Reference to present

- Reduction in low flows
  - Lower water levels
  - Slight increase in salinity and turbidity.
- Artificial breaching at lower than natural levels -> reduction in scouring ->
  - sedimentation in mouth area
  - system open shorter, overall 30% to 22%
- Siltation of upper reaches due to catchment erosion
- Open & brackish states both reduced by more time in closed marine state
- Increased water retention time
- Increased nutrient inputs (farming & WWTW) – incr productivity
- Some habitat loss in marginal areas (development)
- Increased human disturbance (Hermanus, Stanford)
- Fishing impacts
- Regional/global changes in bird populations

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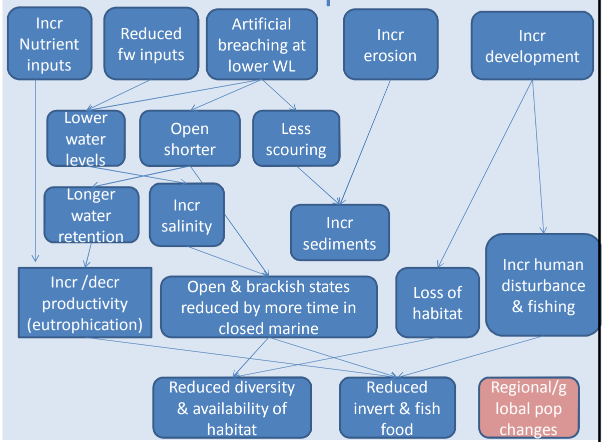
Reference to present



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Reference to present

	Ref	Pres	%	Rationale
Cormorants	42	62	146	Increased salinity and WB cormorant population, possibly not such a large change on average
Wading birds	123	99	80	Reduced fish (60%), decr habitat, disturbance
Herbivorous waterfowl	2728	929	34	Increased salinity, lower water levels, reduced fw subm macrophytes
Other waterfowl	1114	258	23	Increased salinity, lower water levels, reduced emergent veg
Waders	1249	181	15	Reduced open period, loss of upper marsh open habitat?
Gulls & terns	4693	535	11	Human disturbance in mouth area, reduced open period
Birds of prey	3	1	31	Reduction of fish biomass, human disturbance
Kingfishers	21	3	14	Reduced fish biomass, reduced marginal habitat, human disturbance
Total	**9973**	**2067**	21	

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Present ecological status

VARIABLE	SUMMARY OF CHANGE	SCORE	CONF
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
Ave-min		34	
% of impact non-flow related		55	

- Non-flow related impacts
  - Broader **population changes** (increases in Egyptian Goose & wading birds, and general declines in numbers of waders),
  - **Loss of habitat**
  - **Human disturbance** on the estuary
  - **Fishing** (indirect)

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Scenarios

	Reference	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6
Cormorants	42	62	67	62	62	51	41	41
Wading birds	123	99	107	99	99	82	66	66
Herbivorous waterfowl	2728	929	991	962	858	686	515	338
Other waterfowl	1114	258	275	267	238	190	143	94
Waders	1249	181	212	204	174	159	128	118
Gulls & terns	4693	535	594	547	498	381	312	276
Birds of prey	3	1	1	1	1	1	1	1
Kingfishers	21	3	3	3	3	3	2	2

VARIABLE	SCENARIO							
	PRESENT	1	2	3	4	5	6	CONF
1. Species richness	90	95	95	90	85	80	75	L
2 Abundance **(= min score)**	**21**	**23**	**22**	**19**	**16**	**12**	**9**	L
3. Community composition	34	36	35	32	27	22	17	L
Bird scores (ave-min)	**36**	**36**	**34**	**30**	**25**	**21**	**36**	L

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State 1: Open, marine	State 2: Open, gradient	State 3: Partial salinity gradient	State 4: Intermitted pulse	State 5: Freshwater dominated

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