DEVELOPMENT OF CLIMATE CHANGE MITIGATION AND ADAPTATION STRATEGIES FOR SOUTH AFRICA'S ESTUARINE LAKES

L Van Niekerk, S Taljaard, JB Adams, SJ Lamberth, SP Weerts, D Lotter, D Lemley, and T Riddin

Volume III: Vulnerability Assessment Appendices

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COMPILED BY:

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A. VERLORENVLEI

A.1 Predicted Climate Change Scenarios

Predicted climate change scenarios for RCP 4.5 and 8.5 under mid and far future scenarios relevant to Verlorenvlei, are presented in Tables A.1 to A.3 for precipitation in the catchment, precipitation in EFZ and ambient atmospheric temperature, respectively. A summary of broad measures of hydrological changes, as reported by Cullis et al. (2015), is provided in Table A.4.

Table A.1: Verlorenvlei: Predicted change in precipitation in the catchment for RCP 4.5 and 8.5 under mid- and far-future scenarios

CATCHMENT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	-9	-26	45	-30	-18	-3	-14	-14	7	8	-21	26
RCP 4.5 Far	-5	23	-13	-14	-4	-18	-11	-20	-8	-14	-50	64
RCP 8.5 Mid	-11	28	-17	-22	-12	-17	-19	-9	-8	-39	-41	26
RCP 8.5 Far	-30	-30	-28	-59	-39	-25	-44	-11	-36	-50	-60	-36

Table A.2: Verlorenvlei: Predicted change in precipitation in EFZ for RCP 4.5 and 8.5 under mid- and far-future scenarios

ESTUARY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	7	17	26	-33	-14	10	-16	-14	15	16	-31	49
RCP 4.5 Far	9	11	-34	-2	-7	-7	-4	-25	-3	-2	-45	78
RCP 8.5 Mid	-1	28	-32	-33	-14	2	-18	-15	-2	-30	-37	23
RCP 8.5 Far	-34	-61	-65	-63	-28	-14	-44	-13	-27	-40	-57	-53

Table A.3: Verlorenvlei: Predicted increase in ambient atmospheric temperature (°C) for RCP 4.5 and 8.5 under mid- and far-future scenarios for average

TAve	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	1.9	2.1	1.5	2.0	1.3	1.6	1.6	1.6	1.9	1.4	1.8	1.9
RCP 4.5 Far	2.5	2.7	2.3	2.1	1.6	1.7	2.5	2.6	2.7	2.2	2.1	2.4
RCP 8.5 Mid	1.8	2.1	1.8	2.0	2.1	2.4	2.3	1.9	2.3	2.2	2.7	2.1
RCP 8.5 Far	4.1	4.4	3.9	4.3	4.8	4.2	4.3	3.7	4.0	4.0	4.6	3.9
Tmax	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	1.9	2.0	1.8	2.2	1.2	1.6	1.8	1.6	2.0	1.2	1.9	1.9
RCP 4.5 Far	2.5	2.6	2.7	2.3	2.0	1.7	2.9	2.7	2.8	2.1	2.3	2.2
RCP 8.5 Mid	1.5	1.9	2.0	2.0	2.5	2.3	2.4	1.7	2.1	2.2	2.9	1.8
RCP 8.5 Far	3.8	4.2	3.9	4.7	5.2	4.0	4.9	3.7	3.9	3.9	4.8	3.7
Tmin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	1.9	2.3	1.3	1.9	1.4	1.6	1.3	1.5	1.8	1.5	1.7	1.9
RCP 4.5 Far	2.6	2.9	1.9	1.9	1.2	1.6	2.1	2.5	2.7	2.4	1.9	2.6
RCP 8.5 Mid	2.1	2.3	1.5	2.0	1.7	2.5	2.1	2.1	2.5	2.2	2.5	2.4
RCP 8.5 Far	4.4	4.6	4.0	3.9	4.4	4.4	3.7	3.8	4.2	4.1	4.4	4.2

Table A.4: Verlorenvlei: Summary of broad measures of hydrological change (as reported by Cullis et al. 2015)

PARAMETER	PERCENTAGE CHANGE
Median Flows	-15 to -20%
Q 1 (Low flows)	-20%
Q 3 (Floods)	-10 to -15%
Min	-30%
Max	-5% to -10%

Table A.5 provide a summary of potential change in runoff under RCP 4.5 and 8.5 scenarios for mid and far future conditions.

Table A.5: Verlorenvlei: Summary of potential change in runoff under RCP 4.5 and 8.5 scenarios for mid- and far-future conditions

SCENARIO NAME	DESCRIPTION	MAR (x 10^6 m^3)	PERCENTAGE REMAINING
Natural	Reference condition	53.2	
Present	Present	40.2	75.6
Scenario 1	RCP 4.5 Mid	37.2	70.0
Scenario 2	RCP 4.5 Far	35.9	67.5
Scenario 3	RCP 8.5 Mid	35.8	67.4
Scenario 4	RCP 8.5 Far	33.7	63.4

A.2 Abiotic Responses

A.2.1 Abiotic states and key characteristics

The characteristic abiotic states (and associated distinctive temporal patterns) for the Verlorenvlei are illustrated conceptually in Figure A.1.

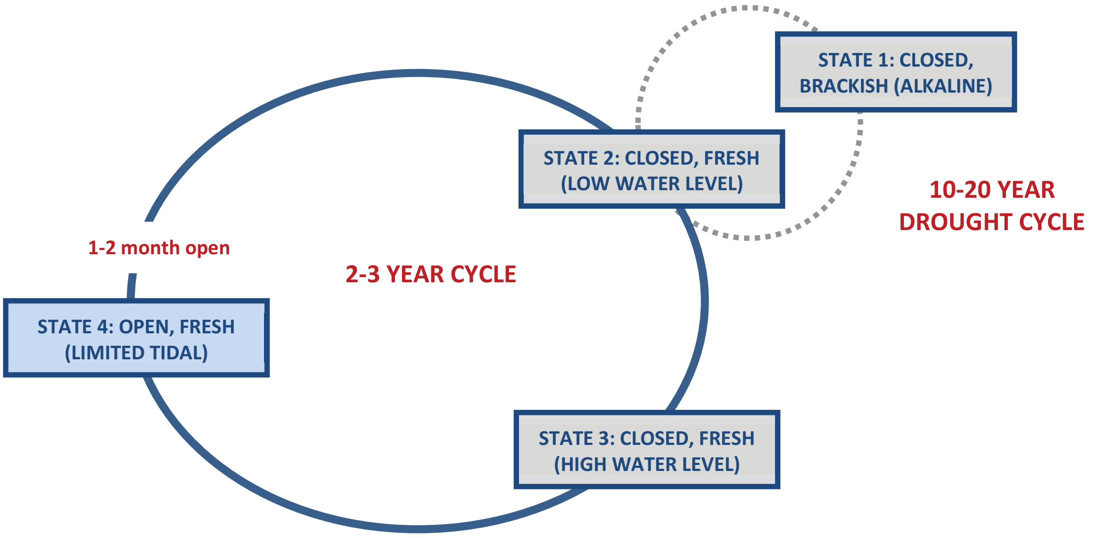


Figure A.1 Verlorenvlei: Typical temporal patterns in the distribution of abiotic states (present)

Verlorenvlei is in a winter rainfall zone. During the dry summer months, the mouth is usually closed. In winters with good rains, the system fills, and the bar is overtopped. The outflowing water scours the sandbar away thus permitting some tidal interaction in Zone A. Tidal exchange continues until the velocity of the outflowing water decrease sufficiently to allow the accretion of sand to form a new bar at the mouth. During storms and high spring tides the sea washes over the sandbar. Seawater is reported to penetrate the main basin as far as Verloren Farm (Robertson 1980). On average the Verlorenvlei breaches every two to three years and remains open between 1 and 2 months after breaching. While low water levels are observed during periods of extended low freshwater inflow, extremely low water levels associated with drought cycles (e.g. 2018/19) are only observed on decadal time scales.

There are four major obstructions to tidal exchange in the lower vlei (Zone A): the mouth; a rocky sill (that used to be a causeway); a causeway below the railway bridge and the road crossing to Elands Bay. In addition to the constrictions in the lower estuary, there are also two causeways in the upper vlei (Zone C) at Grootdrift and Redelinghuys that also pose a constraint to circulation.

Four abiotic states have been identified in the Verlorenvlei Estuary, based on present understanding (Table A.6) with *State 1: Closed, brackish (alkaline)* associated with drought conditions as reflected in water levels below 0.5 m MSL and the formation of hypersalinity (40-50) in the inlet (Zone A), while the main basin (Zone B) salinity is 6 to 10. The shallow upper reaches (Zone C) are dried out. During *State 2: Closed, fresh (low water level)* the mouth of the estuary is closed, with water levels below 1.3 m MSL. Salinity in the inlet channel (Zone A) is hypersaline at 36-40, while the main basin and upper reaches (Zone B and C) are 0. In *State 3: Closed,* fresh *(high water level)* the mouth of the estuary is still closed, with the system at water levels greater than 2.0 m MSL. Salinity in the inlet (Zone A) is between 10 and 15, while the main basin and upper reaches (Zone B and C) are 0. *State 4: Open, fresh (limited tidal exchange)* represent an open mouth state, with the inlet channel under tidal conditions. Water levels are less than 1.3 m MSL. Salinity in the inlet (Zone A) is between 25 and 35, while the main basin and upper reaches (Zone B and C) are 0.

Table A.6: Verlorenvlei: Key abiotic characteristics associated with various abiotic states

STATE	VARIABLE	ZONE A: INLET	ZONE B: BASIN	ZONE C: SHALLOW UPPER REACHES
State 1: Closed, brackish (alkaline)	WL:	<0.5		
	Salinity:	**50**	**6-10**	**Dry**
	Temp:	Summer: ~20-30°C; Winter ~10-20°C		
	WQ:	HM	SM (6)	-
State 2: Closed, fresh (low water level)	WL:	1.0-1.3		
	Salinity:	**40**	**0**	**0**
	Temp:	Summer: ~20-30°C; Winter ~10-20°C		
	WQ:	**HM**	**SM (6)**	**MM**
State 3: Closed, fresh (high water level)	WL:	2.0-3.5		
	Salinity:	**15**	**0**	**0**
	Temp:	Summer: ~20-30°C; Winter ~10-20°C		
	WQ:	**HM**	**SM (5)**	**MM**
State 4: Open, fresh (limited tidal exchange)	WL:	0.5-1.3 m	1.3-2.0	
	Salinity:	**30**	**0**	**0**
	Temp:	Summer: ~20-30°C; Winter ~10-20°C		
	WQ:	**MM**	**SM (5)**	**MM**

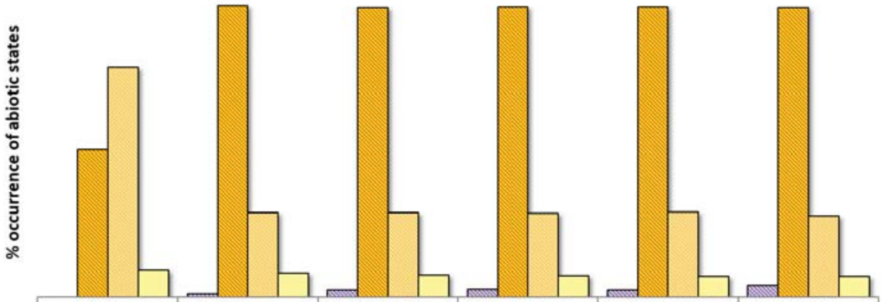
The temperature regime in Verlorenvlei shows a clear seasonal pattern, with summer temperatures (~being markedly higher than those in winter (~10-20°C). The temperature within the system also shows diurnal variation. For example, during warmer months, the morning the water temperature can be relatively low (below 20°C) but can reach 30°C at mid-day as the air temperature rises, especially in the shallower areas that are protected from wind mixing (CSIR 2009).

In its pristine condition Verlorenvlei most likely existed as a well-oxygenated, oligotrophic water body. However, as a result, extensive agricultural activities in the catchment, nutrient input would have increased markedly, as reflected in the increase in dense reed and sedge growth over the years. While the reeds and sedges may well act as effective filters of nutrient input from the catchment to the system, this significant increase growth has most likely created an important secondary source of inorganic nutrients (N), namely *in situ* remineralisations of organic plant debris, typically reflected in inorganic nitrogen being present as NH_4-N species (and not as NO_3-N – which is mostly an indicator of 'new' nitrogen input). Because of long residence times in the basin of the system, low nutrient measurements in this area may not be indicative of oligotrophic conditions, but rather the result of rapid primary production uptake – measurements reflect nett nutrients and not gross nutrient input. The occurrence of cyanobacterial blooms in the basin (Zone B), and at times in Zone C (especially during spring and summer when temperatures are higher and residence times longest) supports this hypothesis. In contrast, measured nutrients in the inlet area (Zine A) are often higher (mainly NH_4-N), but also experienced as less intense algal blooms (based on visual observations) (CSIR 2009).

Because the system is shallow prevailing wind turbulence is sufficient to create a well-mixed, aerated water column despite the high organic loading. However, during dense macrophyte of cyanobacterial blooms (especially in the basin area – Zone B), marked diurnal fluxes in dissolved oxygen can be expected (going from supersaturated during the day to hypoxic at night). Hypoxia (even anoxia) is also a risk when dense macrophyte or algal blooms die off (and wind turbulence is insufficient for effective re-aeration) (CSIR 2009).

A.2.2 Responses to climate change scenarios

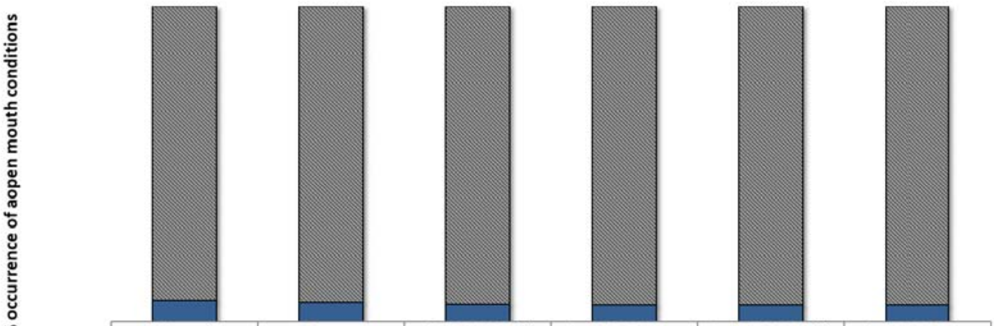
The Verlorenvlei Estuary responds to river flow in all its variability. Breaching is dependent on the total inflow, while the duration of the open period responds largely depends on the level before breaching. Once outflow declines the system closes. Predicted changes in hydrodynamic functioning, average water level, salinity and marine connectivity are captured in the overall occurrence of different abiotic states in the Verlorenvlei are summarised in Figure A.2.



	Natural	Present	Sc1: RCP 4.5 Mid	Sc 2: RCP 4.5 Far	Sc 3: RCP 8.5 Mid	Sc 4: RCP 8.5 Far
State 1: Brackish (alkaline)	0.0	0.9	1.9	2.1	1.9	2.9
State 2: Closed Fresh (High WL)	36.5	72.3	71.8	71.9	71.9	71.8
State 2: Closed Fresh (Low WL)	56.9	20.9	20.9	20.8	21.1	20.1
State 4: Open Fresh	6.7	6.0	5.5	5.3	5.2	5.2

Figure A.2: Verlorenvlei: Occurrence of different abiotic states under different scenarios

Mouth conditions showed limited sensitivity to the changes in river flow to the estuary (Figure A.3 and Table A.7). Under Scenario 1 to 4, mouth open conditions decline progressively, with most of the decline in connectivity occurring between May and September. Scenario 4 shows the most decline in open conditions from the present.



	Natural	Present	Sc1: RCP 4.5 Mid	Sc 2: RCP 4.5 Far	Sc 3: RCP 8.5 Mid	Sc 4: RCP 8.5 Far
Closed	93.3	94.0	94.5	94.7	94.8	94.8
Open	6.7	6.0	5.5	5.3	5.2	5.2

Figure A.3: Verlorenvlei: Overall occurrence of open mouth conditions (expressed as % open) under different scenarios

Table A.7: Verlorenvlei: Estimated percentage time estuary is connected to sea under different scenarios (darker colours indicate high connectivity and light colours low connectivity)

VERLOREN:	PRESENT			SCENARIO 1			SCENARIO 2			SCENARIO 3			SCENARIO 4		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
SEASONAL DISTRIBUTION (85 YEAR SIMULATION PERIOD)															
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
May	7	7	7	6	6	6	7	7	7	6	6	6	6	6	6
June	18	18	18	15	15	15	14	14	14	14	14	14	14	14	14
July	20	20	20	18	18	18	18	18	18	18	18	18	18	18	18
August	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
September	8	8	8	8	8	8	6	6	6	6	6	6	6	6	6
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PERCENTILE DISTRIBUTION (85 YEAR SIMULATION PERIOD)															
99%ile	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
95%ile	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
90%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
80%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
70%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
60%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
50%ile (median)	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
40%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
30%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
20%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
10%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
5%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
1%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C

Average water levels for Scenario 1 to 3 are similar to the present, only showing a 10 cm decline under Scenario 4. A broad summary is provided Table A.8.

Table A.8: Verlorenvlei: Predicted water levels (m) under Present State and Future Climate Change Scenarios

VERLOREN:	PRESENT			SCENARIO 1			SCENARIO 2			SCENARIO 3			SCENARIO 4		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
SEASONAL DISTRIBUTION (85 YEAR SIMULATION PERIOD)															
January	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
February	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
March	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
April	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
May	1.1	1.2	1.2	1.1	1.2	1.2	1.1	1.2	1.2	1.1	1.2	1.2	1.1	1.1	1.1
June	1.3	1.4	1.4	1.3	1.4	1.4	1.3	1.4	1.4	1.3	1.4	1.4	1.3	1.4	1.4
July	1.4	1.6	1.6	1.4	1.6	1.6	1.4	1.6	1.6	1.4	1.6	1.6	1.3	1.5	1.5
August	1.4	1.6	1.6	1.4	1.6	1.6	1.4	1.6	1.6	1.4	1.6	1.6	1.4	1.6	1.6
September	1.2	1.3	1.3	1.2	1.3	1.3	1.2	1.3	1.3	1.2	1.3	1.3	1.2	1.3	1.3
October	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
November	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
December	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
PERCENTILE DISTRIBUTION (85 YEAR SIMULATION PERIOD)															
99%ile	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
95%ile	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
90%ile	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
80%ile	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
70%ile	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
60%ile	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
50%ile (median)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
40%ile	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
30%ile	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20%ile	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10%ile	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5%ile	0.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1%ile	0.3	1.0	1.0	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5

Salinity regimes under Scenario 1 to 3 are very similar to the present. There is a slight increase in salinity under scenario 4. A summary of the result is presented in Table A.9.

Table A.9: Verlorenvlei: Predicted salinity under Present State and Future Climate Change Scenarios

VERLOREN:	PRESENT			SCENARIO 1			SCENARIO 2			SCENARIO 3			SCENARIO 4		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
SEASONAL DISTRIBUTION (85 YEAR SIMULATION PERIOD)															
January	40	0	0	40	0	0	40	0	0	40	0	0	40	0	0
February	40	0	0	40	0	0	40	0	0	40	0	0	40	0	0
March	40	0	0	40	0	0	40	0	0	40	0	0	40	0	0
April	39	0	0	40	0	0	39	0	0	39	0	0	40	0	0
May	34	0	0	34	0	0	34	0	0	34	0	0	35	0	0
June	26	0	0	26	0	0	26	0	0	26	0	0	26	0	0
July	22	0	0	22	0	0	22	0	0	22	0	0	24	0	0
August	21	0	0	21	0	0	21	0	0	21	0	0	21	0	0
September	30	0	0	30	0	0	30	0	0	30	0	0	30	0	0
October	39	0	0	39	0	0	39	0	0	39	0	0	39	0	0
November	40	0	0	40	0	0	40	0	0	40	0	0	40	0	0
December	40	0	0	40	0	0	40	0	0	40	0	0	40	0	0
PERCENTILE DISTRIBUTION (85 YEAR SIMULATION PERIOD)															
99%ile	40	0	0	50	6	0	50	6	0	50	6	0	50	6	0
95%ile	40	0	0	40	0	0	40	0	0	40	0	0	40	0	0
90%ile	40	0	0	40	0	0	40	0	0	40	0	0	40	0	0
80%ile	40	0	0	40	0	0	40	0	0	40	0	0	40	0	0
70%ile	40	0	0	40	0	0	40	0	0	40	0	0	40	0	0
60%ile	40	0	0	40	0	0	40	0	0	40	0	0	40	0	0
50%ile (median)	40	0	0	40	0	0	40	0	0	40	0	0	40	0	0
40%ile	40	0	0	40	0	0	40	0	0	40	0	0	40	0	0
30%ile	40	0	0	40	0	0	40	0	0	40	0	0	40	0	0
20%ile	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
10%ile	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
5%ile	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
1%ile	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0

Predicted changes in seasonal and percentile distribution of water quality under present and future Climate Change scenarios are provided in Table A.10. Present water quality in the Verlorenvlei has been significantly modified by anthropogenic pollution inputs, in this case mostly agricultural return flow. It is unlikely that the predicted shifts in rainfall and temperature, associated with the future Climate Change Scenarios, will cause measurable shifts from the Present State.

Table A.10: Verlorenvlei: Predicted water quality under Present State and Future Climate Change Scenarios

	VERLORENVLEI: PRESENT			VERLORENVLEI: SCENARIO 1			VERLORENVLEI: SCENARIO 2			VERLORENVLEI: SCENARIO 3			VERLORENVLEI: SCENARIO 4		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
SEASONAL DISTRIBUTION (SIMULATION PERIOD)															
January	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
February	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
March	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
April	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
May	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
June	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3
July	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3
August	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3
September	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
October	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
November	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
December	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)															
95%ile	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
90%ile	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
80%ile	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
70%ile	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
60%ile	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
50%ile (median)	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
40%ile	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
30%ile	4	6	3	4	6	3	4	6	3	4	6	3	4	6	3
20%ile	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3
10%ile	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3

A.3 Biotic Responses

A.3.1 Microalgae

The conceptual model for microalgal characteristics under different abiotic scenarios is illustrated in Figure A.4, while the microalgal characteristics associated with different zone are summarised in Table A.11. Phytoplankton biomass is highest during periods of mouth closure, low freshwater inflow, and increased nutrient availability. As such, bloom conditions (~Poor: ≥ 20 but < 60 µg/ℓ) can be expected in Zone A and B associated with low water levels and degraded water quality (State 1 and 2). Despite a lack of available data, benthic microalgal biomass is expected to peak during closed, shallow and brackish conditions (State 1) due to increased light availability and water residency. As water levels (State 3) and exchange (State 4) increase, phytoplankton and benthic microalgal biomass would be expected to decrease throughout the system due to dilution and increased water depths, respectively.

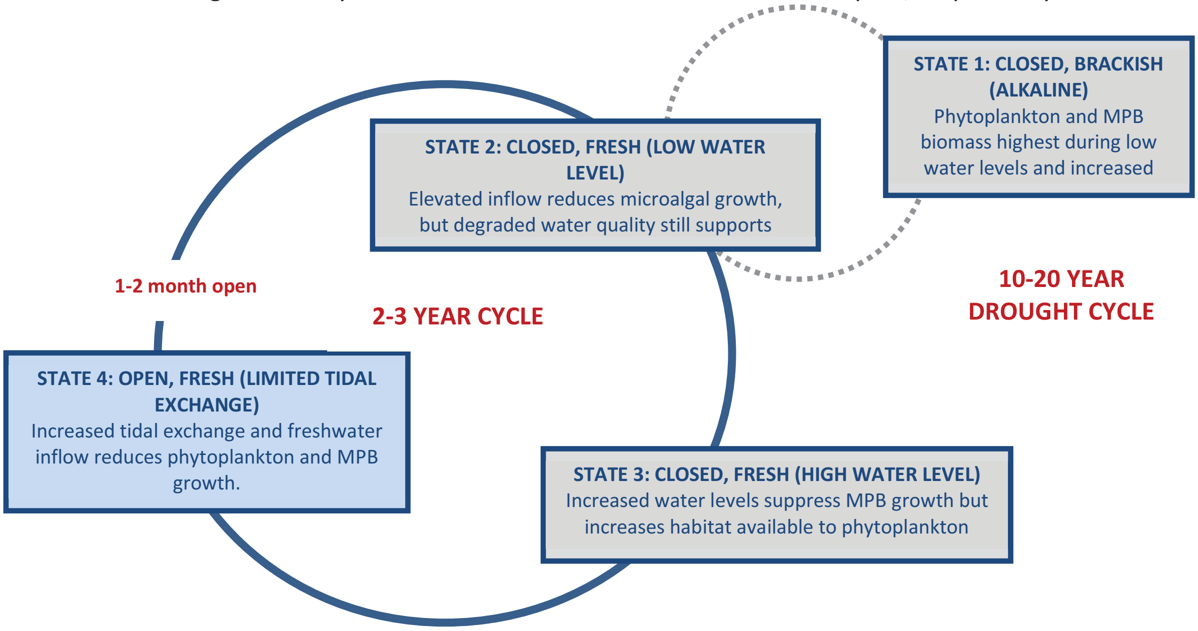


Figure A.4: Verlorenvlei: Microalgae Conceptual model

Harmful algal species, such as *Microcystis aeruginosa* (cyanobacteria, salinity tolerance up to ~15), have been recorded in the system since the 1980s (Sinclair et al., 1986) in conjunction with oligohaline conditions, and would therefore be expected to be present in the system (~predominantly Zone B) regardless of the abiotic state.

Table A.11: Verlorenvlei: Key microalgal characteristics associated with various abiotic states

STATE	PARAMETER	ZONE A: INLET	ZONE B: BASIN	ZONE C: SHALLOW UPPER REACHES
State 1: Closed, brackish (alkaline)	Phytoplankton:			-
	Benthic microalgae:			-
	Harmful algae:			-
State 2: Closed, fresh (low water level)	Phytoplankton:			
	Benthic microalgae:			
	Harmful algae:			
State 3: Closed, fresh (high water level)	Phytoplankton:			
	Benthic microalgae:			
	Harmful algae:			
State 4: Open, fresh (limited tidal exchange)	Phytoplankton:			
	Benthic microalgae:			
	Harmful algae:			

Confidence levels: Phytoplankton – Medium; Benthic microalgae – Low; Harmful algae – Medium

A summary of the key responses in microalgae under the Present State and Future Climate Change scenarios are summarized in Table A.12.

Table A.12: Verlorenvlei: Predicted Microalgae responses under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Reduced freshwater inflow and increased nutrient availability has facilitated an increase in microalgal growth, particularly in Zone A (benthic microalgae) and B (phytoplankton). Although an infrequent occurrence, open mouth conditions and elevated freshwater inflows serve to dilute microalgal biomass.
1-3	The marginal reductions in freshwater inflow predicted for these scenarios are not expected to result in any marked increases in microalgal growth. This is due to the system already experiencing prolonged periods of little to no freshwater inflow.
4	Increased temperature, prolonged periods of mouth closure, increased salinity, and a 10 cm reduction in water levels are expected to facilitate increased phytoplankton blooms (including HABs, e.g. *Microcystis aeruginosa*) and the accumulation of benthic microalgae in shallow areas.

Predicted changes in seasonal and percentile distribution of microalgae under present and future Climate Change scenarios are provided in Tables A.13 to A.15.

Table A.13: Verlorenvlei: Predicted Phytoplankton responses under Present State and Future Climate Change Scenarios

	VERLORENVLEI: PRESENT			VERLORENVLEI: SCENARIO 1			VERLORENVLEI: SCENARIO 2			VERLORENVLEI: SCENARIO 3			VERLORENVLEI: SCENARIO 4		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
SEASONAL DISTRIBUTION (SIMULATION PERIOD)															
January	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
February	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
March	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
April	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
May	4	4	3	4	4	3	4	4	3	4	4	3	4	5	3
June	3	4	2	3	4	2	3	4	2	3	4	2	3	4	3
July	3	4	2	3	4	2	3	4	2	3	4	2	3	4	3
August	3	4	2	3	4	2	3	4	2	3	4	2	3	4	3
September	3	4	2	3	4	2	3	4	2	3	4	2	4	5	3
October	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
November	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
December	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)															
95%ile	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
90%ile	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
80%ile	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
70%ile	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
60%ile	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
50%ile (median)	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
40%ile	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
30%ile	4	4	3	4	4	3	4	4	3	4	4	3	5	5	3
20%ile	3	4	2	3	4	2	3	4	2	3	4	2	3	4	3
10%ile	3	4	2	3	4	2	3	4	2	3	4	2	3	4	3

Table A.14: Verlorenvlei: Predicted Benthic microalgae responses under Present State and Future Climate Change Scenarios

	VERLORENVLEI: PRESENT			VERLORENVLEI: SCENARIO 1			VERLORENVLEI: SCENARIO 2			VERLORENVLEI: SCENARIO 3			VERLORENVLEI: SCENARIO 4		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
SEASONAL DISTRIBUTION (SIMULATION PERIOD)															
January	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
February	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
March	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
April	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
May	4	2	3	4	2	3	4	2	3	4	2	3	4	3	3
June	3	2	3	3	2	3	3	2	3	3	2	3	4	2	3
July	3	1	3	3	1	3	3	1	3	3	1	3	3	2	3
August	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3
September	3	2	3	3	2	3	3	2	3	3	2	3	4	3	3
October	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
November	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
December	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)															
95%ile	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
90%ile	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
80%ile	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
70%ile	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
60%ile	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
50%ile (median)	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
40%ile	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
30%ile	4	3	3	4	3	3	4	3	3	4	3	3	5	4	3
20%ile	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3
10%ile	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3

Table A.15: Verlorenvlei: Predicted Harmful algae responses under Present State and Future Climate Change Scenarios

	VERLORENVLEI: PRESENT			VERLORENVLEI: SCENARIO 1			VERLORENVLEI: SCENARIO 2			VERLORENVLEI: SCENARIO 3			VERLORENVLEI: SCENARIO 4		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
SEASONAL DISTRIBUTION (SIMULATION PERIOD)															
January	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
February	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
March	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
April	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
May	3	4	2	3	4	2	3	4	2	3	4	2	3	4	3
June	2	3	2	2	3	2	2	3	2	2	3	2	3	3	2
July	2	3	1	2	3	1	2	3	1	2	3	1	2	3	2
August	2	3	1	2	3	1	2	3	1	2	3	1	2	3	2
September	2	3	2	2	3	2	2	3	2	2	3	2	3	4	2
October	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
November	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
December	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)															
95%ile	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
90%ile	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
80%ile	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
70%ile	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
60%ile	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
50%ile (median)	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
40%ile	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
30%ile	3	4	3	3	4	3	3	4	3	3	4	3	4	4	3
20%ile	2	3	1	2	3	1	2	3	1	2	3	1	2	3	2
10%ile	2	3	1	2	3	1	2	3	1	2	3	1	2	3	2

A.3.2 Macrophytes

Cover abundance in the different zones of the estuary are dependent on salinity and water level, as well as groundwater. Along the length of the lake there is a transition from saline habitat near the mouth (Zone A) to freshwater habitat (Zones B and C). Zone A is separated from Zone B via a causeway and rocky sill. Reeds and sedges are particularly abundant in Zone B. Salt marsh and saline grasses habitat includes *Salicornia, Sarcocornia natalensis, Bassia diffusa, Sporobolus virginicus, Cynodon dactylon, Paspalum vaginatum, Triglochin* spp., *Cotula* species as well as *Juncus kraussii* which occurs on the higher elevation. Reeds and sedges are represented mainly by *Phragmites australis* along with *Scirpus maritimus, Typha capensis* and various *Cyperus* species. Salinity, water depth and groundwater salinity determine the cover abundance of reeds. They occur at water depths between 0 to 2 m and *Phragmites australis* has the higher salinity tolerance (up to 20). When water salinity drops to below 10 bulrush, *Typha capensis* is common. Reeds show a seasonal die back in winter. During the late 1980s *Myriophyllum spicatum*, a submerged macrophyte, dominated large areas of the lake where the water was less than 2m deep (Sinclair et al. 1986) but has not been recorded recently. The estuary may have transitioned to an alternate state dominated by microagal blooms (*Microcystis aeruginosa*) due to nutrient enrichment. Although future scenarios will result in a reduction in freshwater inflow, this will have little effect on the estuary as it already receives little to zero flow. However higher temperature and increase in winds will lead to an increase in evaporation, drying out of habitats, salinization and lower water level. Groundwater input will likely also decrease due to abstraction negatively influencing the surrounding reeds and sedges. The upstream Redelinghuys wetlands have also been impacted by freshwater abstraction and burning which destroyed part of the peat zone. The macrophyte conceptual model for Verlorenvlei is presented in Figure A.5.

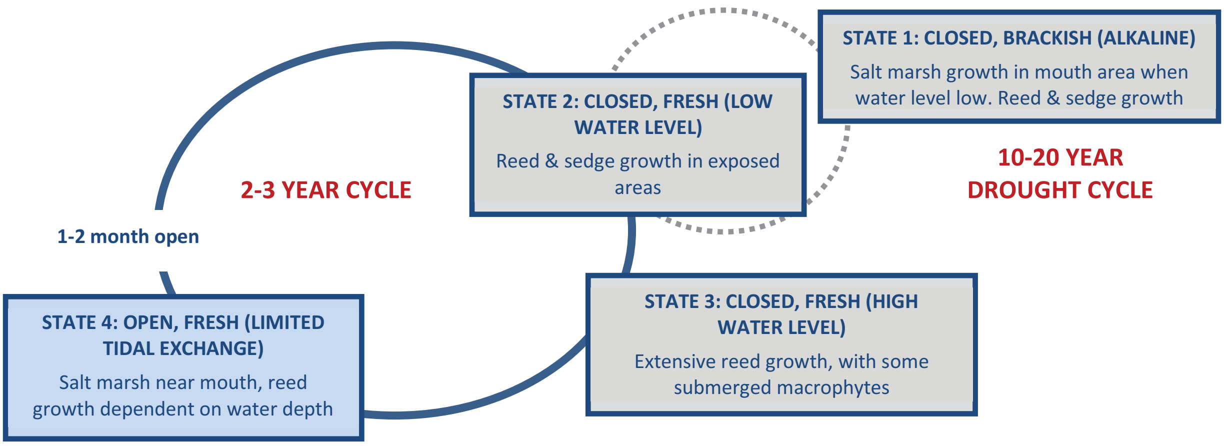


Figure A.5: Verlorenvlei: Macrophyte Conceptual model

Table 9.16 summarises the predicted responses in Microphytes under Present and Future Climate Change scenarios.

5 February 2003: High water (1.2 MSL), main basin full and reeds visible

9 February 2020: Low water level (0 MSL), reeds exposed

(Photo: Felicity Strange)

Table A.16: Verlorenvlei: Predicted macrophytes responses under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present Largely modified	There has been a loss of riparian vegetation due to farming activities and roads, grazing of salt marsh and reeds and regular burning of reeds. Decrease in freshwater inflow has led to general dying out of the macrophyte habitats due to extended periods of zero flow. Saline habitats near the mouth have increased in salinity and there is a disconnect between the different water bodies. The low water level and nutrient input from surrounding agricultural activities have promoted growth of reeds and sedges in Zone B.
1-3	Large future reduction in freshwater inflow, however, there is already zero inflow. The estuary continues to cycle between the closed fresh low water level and closed fresh high water level states. However higher temperature and increase in winds will lead to an increase in evaporation, drying out of habitats, salinization and lower water level. Groundwater input will likely also decrease due to abstraction negatively influencing the surrounding reeds and sedges.
4	The increase in temperature is likely to increase macroalgal blooms in the estuary and lead to further evaporation and drying out of the system.

A.3.3 Fish

A total of 14 fish species from 9 families has been recorded from Verlorenvlei and a further two are expected to occur Four (25%) of these are entirely dependent on estuaries to complete their lifecycles. One, the estuarine round-herring *Gilchristella aestuaria*, breeds and spends its entire lifecycle in the estuarine environment whereas three, the white steenbras *Lithognathus lithognathus*, flathead mullet *Mugil cephalus* and freshwater mullet *Myxus capensis* are dependent on estuaries as nursery areas for at least their first year of life. In addition, *Myxus capensis* and to a lesser extent, *Mugil cephalus* are facultative catadromous species that require estuaries as transit routes between the marine and freshwater environment. A further three (19%) species namely the harder *Liza richardsonii*, white stumpnose *Rhabdosargus globiceps* and Knysna sand-goby *Psammogobius knysnaensis* are at least partially dependent on estuaries. In all, 44% of the fish species recorded, or expected to occur, in Verlorenvlei can be regarded as either partially or completely dependent on estuaries for their survival. All 9 (56%) of the remaining species are euryhaline freshwater species whose penetration into estuaries is determined by salinity tolerance. Three of these, the Cape galaxias *zebratus*, Cape kurper *Sandelia capensis* and Berg River Redfin *Pseudobarbus bergi* are endemic to the southwestern Cape. Six, the Mozambique Tilapia *Oreochromis mossambicus*, carp *Cyprinus carpio*, banded tilapia *sparrmanii*, smallmouth bass *Micropterus dolomieu*, largemouth bass *Micropterus salmoides* and tench *Tinca tinca* are introduced species. The fish conceptual model for Verlorenvlei is presented in Figure A.6, while predicted responses are presented in Table A.17.

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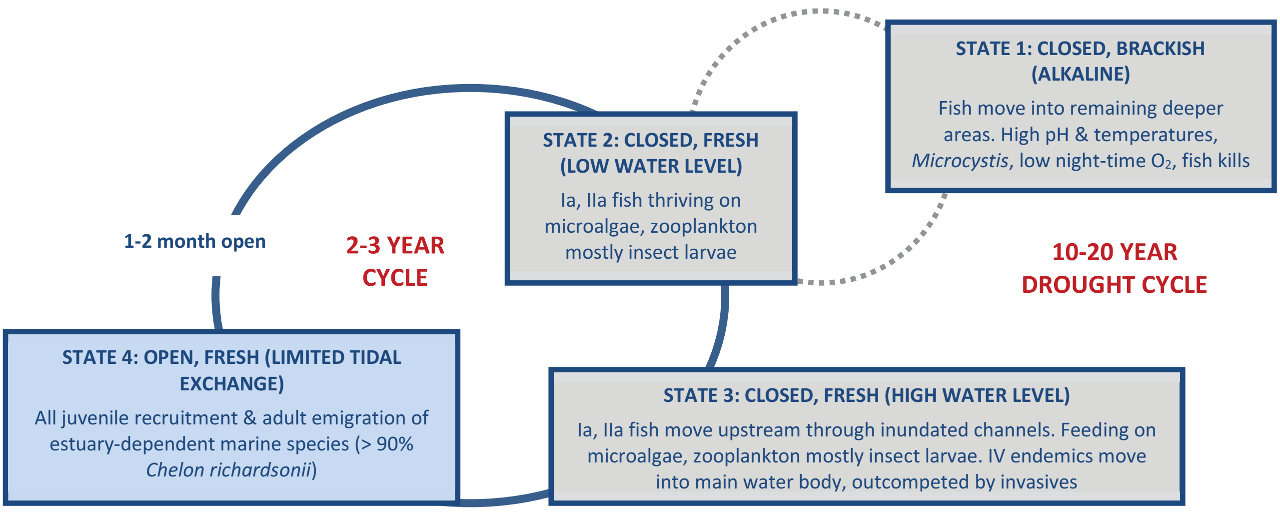


Figure A.6: Verlorenvlei: Fish Conceptual model

Table A.17: Verlorenvlei: Predicted fish responses under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Drought, low water levels have resulted in zero recruitment or emigration of estuary-dependent marine species and population/s in lower, main basin and upper reaches have become isolated. Reed bed and other macrophyte refugia are no longer inundated and/or available to fish and fish kills from low oxygen, high temperatures and stranding are a regular occurrence. These are typically 10-20 year drought cycle State 1 conditions
1-3	Future reduction in freshwater inflow sees an increase in the frequency and duration of State 2 closed fresh conditions further limiting recruitment or emigration of estuarine opportunists and obligate estuary-dependent marine species. Except for flathead mullet *Mugil cephalus*, recruitment of the latter obligate fish is already functionally zero. Recruitment of marine opportunists mostly harder *Chelon richardsonii* (> 90%) will still occur but be unpredictable and at best once every 5-10 years. Estuarine-resident *Gilchristellla aestuaria* will continue to breed in the system but also be subject to fish kills at very low water levels. During State 2 low and State 3 high water levels, all these estuary-residents, dependent and opportunists will thrive feeding on Microcystis blooms. However, invasive *Oreochromis mossambicus* and carp *Cyprinus carpio* biomass also increase at this time, outcompeting most indigenous species.
4	An increase in the frequency and duration of State 1 drought conditions, as experienced in the Present day, will see zero recruitment or emigration of marine species and isolation of those already in the system. Loss of reed, macrophytes habitat and refugia and fish kills from low oxygen, high temperatures and stranding are a regular occurrence

B. BOT/KLEINMOND

B.1 Predicted Climate Change Scenarios

Predicted climate change scenarios for RCP 4.5 and 8.5 under mid and far future scenarios relevant to Bot/Kleinmond, are presented in Tables B.1 to B.3 for precipitation in the catchment, precipitation in EFZ and ambient atmospheric temperature, respectively. A summary of broad measures of hydrological changes, as reported by Cullis et al. (2015), is provided in Table B.4.

Table B.1: Bot/Kleinmond: Predicted change in precipitation (relative percentage change) in catchment for RCP 4.5 and 8.5 under mid- and far-future scenarios

CATCHMENT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	-8	-17	-6	-39	-17	-13	-16	-16	-3	24	-23	-12
RCP 4.5 Far	7	-15	-7	-8	-6	-16	-23	-8	-20	14	-23	1
RCP 8.5 Mid	5	-14	9	-22	-17	-15	-22	-29	-15	-20	-11	-3
RCP 8.5 Far	-10	-40	-6	-27	-25	-22	-41	-26	-26	-38	-32	-16

Table B.2: Bot/Kleinmond: Predicted change in precipitation in EFZ for RCP 4.5 and 8.5 under mid- and far-future scenarios

ESTUARY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	-22	-10	-8	-44	-19	-15	-5	-7	-13	17	-26	-16
RCP 4.5 Far	0	-13	9	-19	4	-20	-15	-11	-21	11	-18	-1
RCP 8.5 Mid	-11	-9	28	-23	-19	-20	-17	-30	-23	-19	-4	-8
RCP 8.5 Far	-18	-40	-10	-33	-11	-21	-37	-19	-31	-38	-31	-17

Table B.3: Bot/Kleinmond: Predicted increase in ambient atmospheric temperature (°C) for RCP 4.5 and 8.5 under mid- and far-future scenarios for average

TAve	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	1.6	1.4	1.3	2.0	1.6	1.9	1.5	1.4	1.8	1.6	1.5	1.9
RCP 4.5 Far	1.9	2.0	1.8	2.2	1.5	1.9	2.2	2.6	2.6	2.3	1.9	2.4
RCP 8.5 Mid	1.7	1.6	1.6	2.2	1.9	2.5	2.2	2.1	2.5	2.7	2.3	2.3
RCP 8.5 Far	4.0	3.7	3.5	4.0	4.6	4.1	4.0	3.8	4.1	4.4	4.2	3.9
Tmax	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	1.2	1.0	1.3	2.4	1.7	2.1	1.5	1.3	1.9	1.4	1.7	2.0
RCP 4.5 Far	1.5	1.7	1.8	2.5	1.7	1.8	2.5	2.7	3.0	2.2	2.1	2.3
RCP 8.5 Mid	1.1	1.3	1.5	2.2	2.1	2.6	2.4	2.2	2.9	2.8	2.5	2.2
RCP 8.5 Far	3.5	3.3	3.2	4.1	4.8	4.2	4.4	3.8	4.2	4.6	4.5	3.6
Tmin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	2.1	1.8	1.3	1.7	1.5	1.7	1.5	1.6	1.7	1.8	1.3	1.8
RCP 4.5 Far	2.3	2.3	1.7	2.0	1.2	1.9	1.9	2.5	2.2	2.4	1.7	2.5
RCP 8.5 Mid	2.3	1.9	1.6	2.2	1.8	2.4	1.9	2.1	2.1	2.6	2.1	2.4
RCP 8.5 Far	4.4	4.1	3.9	3.9	4.4	4.1	3.7	3.8	3.9	4.2	3.9	4.1

Table B.4: Bot/Kleinmond: Summary of broad measures of hydrological change (as reported by Cullis et al. 2015)

PARAMETER	PERCENTAGE CHANGE
Median Flows	-15%
Q 1 (low flows)	-20%
Q 3 (Floods)	-10%
Min	-25 to -30%
Max	-5%

Table B.5 provide a summary of potential change in runoff under RCP 4.5 and 8.5 scenarios for mid and far future conditions.

Table B.5: Summary of potential change in the runoff to the Bot/Kleinmond Estuary under RCP 4.5 and 8.5 scenarios for mid and far future conditions to the Bot/Kleinmond Estuary

SCENARIO NAME	DESCRIPTION	MAR (x 10^6 m^3)	PERCENTAGE REMAINING
Natural	Reference condition	89.0	
Present	Present	72.0	80.9
Scenario 1	RCP 4.5 Mid	64.9	72.9
Scenario 2	RCP 4.5 Far	63.8	71.7
Scenario 3	RCP 8.5 Mid	60.0	67.4
Scenario 4	RCP 8.5 Far	56.1	63.0

B.2 Abiotic Responses

B.2.1 Abiotic states and key characteristics

The characteristic abiotic states (and associated distinctive temporal patterns) for the Bot/Kleinmond are illustrated conceptually in Figure B.1.

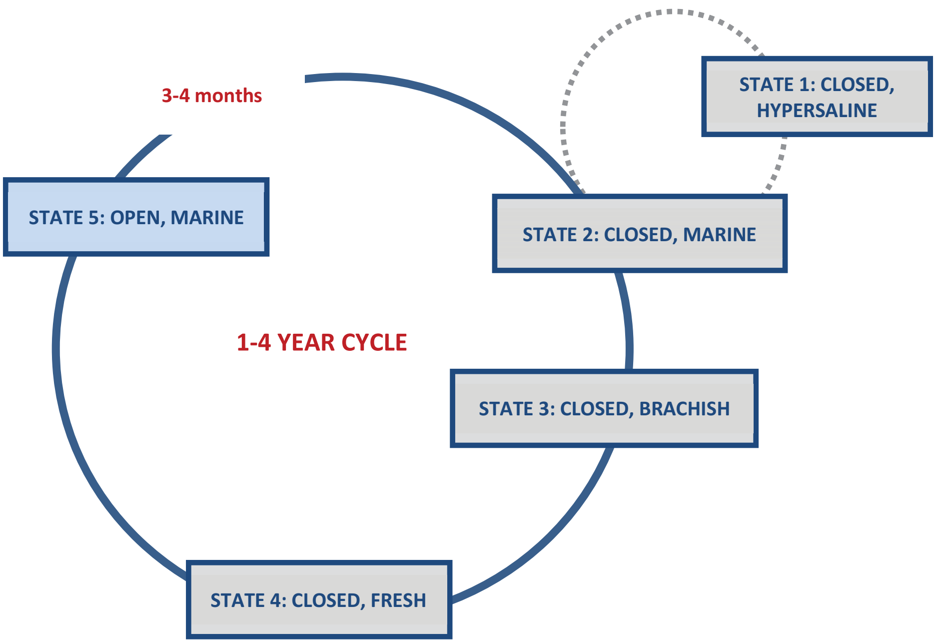


Figure B.1: Bot/Kleinmond: Distinctive temporal patterns in the distribution of abiotic states (present)

When closed the water level in the Bot system depends on the balance of the inflow (+) and the outflow (-) (Figure B.2). The inflow is dependent on rainfall and the run-off and from the catchment and the outflow on what flows through the Bot/Kleinmond mouth, seepage and evaporation. At levels of ~1.7 m MSL the Bot and Kleinmond systems are connected (Koop 1982). The natural breaching level of Kleinmond is ~2.5 m MSL. This is based on the level that the berm of the Bot breached at naturally in the year 2000 after there had been no intervention in its natural mouth dynamics. The natural breaching level of Botvlei is estimated to be about ~3.0 m MSL (Van Niekerk et al. 2000). The Bot closes at a water level of approximately 0.6 m MSL.

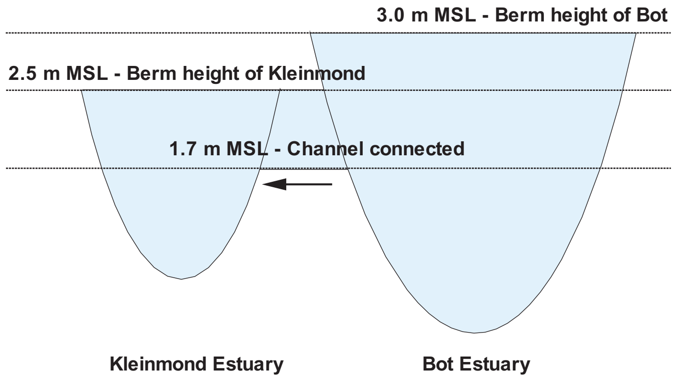


Figure B.2: Bot/Kleinmond: Illustration of various water levels

At about 1.7 m MSL the two systems become connected via the outflow channel. If the Kleinmond is then open, water flows from Bot to Kleinmond and out to sea. The Bot can only open if the river inflow is greater than the outflow through the Kleinmond mouth. The total amount of water required to breach the Botvlei is thus strongly dependant on the amount lost to the Kleinmond. The more water is lost through the Kleinmond mouth, the more water is needed for the Bot to breach. Therefore, premature openings at Kleinmond reduce the possibility of breaching at Botvlei considerably and are one of the critical factors for the Bot not breaching as often as it should in the past. On average the Bot Estuary breaches every 1 to 4 years and remains open about 4 months after breaching. The system breaches the most frequently in late winter, with more than 30% of past Bot breaching having occurred in August. Under normal rainfall conditions Kleinmond can breach at annual time scales.

The Kleinmond mouth can breach nearly annually given its small size relative to the Lamloch River, however, unless supported by outflow from the larger Bot system, this mouth will close within weeks of breaching. During droughts, the system can remain closed for up to four years.

The system was sub-divided into five distinct zones using bathymetry (size and shape) and salinity distributions as indicators of more homogenous sections (Van Niekerk et al. 2010).

- **Zone A: Upper Basin** – This zone of the Botvlei is a narrow, confined channel (~3 m deep) opening up into a wide, shallow basin (~1 m deep).
- **Zone B: Middle Basin** – This zone comprises a smaller, shallow basin with depths varying between 0.5 to 1m, depending on water levels in the system.
- **Zone C: Lower Basin** – This zone of the Botvlei represents the large, main water body with depths varying between 2 to 3m, depending on water levels in the system.
- **Zone D: Rooisand Wetlands** – This area comprises a wetland connecting Bot with the Kleinmond. This zone becomes exposed when water levels in the Botvlei are low. When this area is inundated water depth is on average about 0.5 m.
- **Zone E: Lower estuary (Bot/Kleinmond)** – This zone comprises the much smaller Kleinmond.

Five abiotic states (Table B.6) have been identified in the Bot/Kleinmond Estuary, with *State 1: Closed, hypersaline* associated with drought conditions and generally within a year after mouth closure. Water level would be below 0.5 m MSL, with Rooisand (Zone D) exposed. Hypersalinity (40) would be observed in the main water body (Zone B and C) of the system, while Bot/Kleinmond (Zone E) is expected to be near marine at 25 to 30. During *State 2: Closed, marine* the mouth of the estuary has been closed for less than a year, with water levels below 1.3 m MSL. Salinity in the main basins and Rooisand (Zone A to C) is greater than 30, and between 25 and 30 in the upper basin and about 10 in Bot/Kleinmond (Zone E). In *State 3: Closed, brackish* the mouth of the estuary has been closed between 1 and 3 years, with the system at water levels between 1.3 and 2.5 m MSL. Salinity in the basin (Zone A to C) is between 10 and 20, while Bot/Kleinmond (Zone E) is between 10 and 20 (if open). Under *State 4: Closed, fresh* the mouth of the estuary has been closed for more than 3 years, with the system at water levels between 1.5 and 3.0 m MSL. Salinity is between 1 and 5 in all zones. *State 5: Open, Marine* represents an open mouth state, with the system under tidal conditions. The upper basin (Zone A) will be between 10 and 20, the middle basin (Zone B) between 25-30, the lower basin (Zone C) about 30 to 35, Rooisand (Zone D) will be exposed, while Bot/Kleinmond (Zone E) will be brackish at 15.

Table B.6: Bot/Kleinmond: Key abiotic characteristics associated with various states

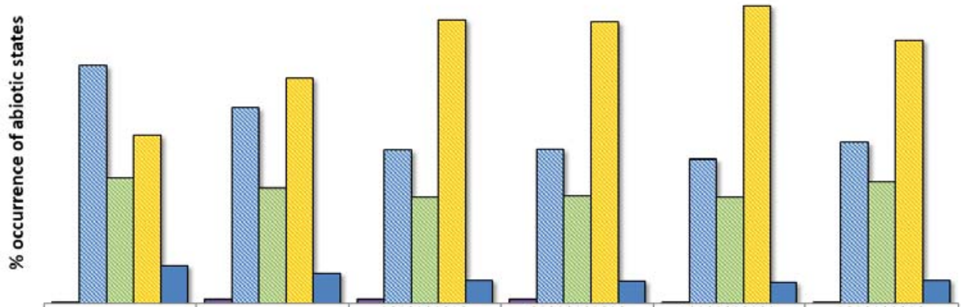
STATE	PARAMETER	ZONE A	ZONE B	ZONE C	ZONE D	ZONE E
State 1: Closed, hypersaline 1 (closed < 1 year followed by drought)	WL:	0-0.5				
	Salinity:	25-30	40	40	Exposed	15
	Temp:	Average summer: 23.6°C; Average winter: 11.9°C				
	WQ:	HM	HM	MM	-	NN
State 2: Closed, marine (closed < 1 year)	WL:	0.5-1.3 m MSL				
	Salinity:	25	35	35	30	10
	Temp:	Average summer: 23.6°C; Average winter: 11.9°C				
	WQ:	HM	HM	MM	NN	NN
State 3: Closed, brackish (closed between 1-3 years)	WL:	1.3-2.5m MSL				
	Salinity:	10	10-20	10-20	10-20	15-20 (if open)
	Temp:	Average summer: 23.6°C; Average winter: 11.9°C				
	WQ:	HM	HM	MM	NN	NN
State 4: Closed, fresh (closed > 3 years)	WL:	1.5-3.0 m MSL				
	Salinity:	1	5	5	5	5
	Temp:	Average summer: 23.6°C; Average winter: 11.9°C				
	WQ:	SM)	SM	HM	HM	HM
State 5: Open, marine (open ~ 4 months of year)	WL:	0.0-1.0 m MSL, tidal range between 15-25 cm, but can vary 0.1-1.0 m MSL after breaching				
	Salinity:	10-20	25-30	35	Exposed	15
	Temp:	Average summer: 23.6°C; Average winter: 11.9°C				
	WQ:	HM	HM	HM	-	NN

The catchment of the Bot/Kleinmond system supports agricultural land use introducing higher nutrient input especially during periods of high flows (i.e. fresher states). The Bot River WWTW near the N2 also discharges into the Bot River, at a point 13.5 km upstream of the Bot River Bridge on the R43, at the head of the estuary. Treated effluent from the Hawston WWTW is discharged into the Paddavlei wetlands, which channel stormwater from Hawston. The influence of these sources is observed in the middle and upper part of the Bot system (Zones A and B) when salinities are lower, reflecting the significant influence of fresher waters (river of WWTW). Increased reed growth, specifically along the shores of the middle reaches, is probably indicative of nutrient seepage associated with diffuse inputs from adjacent areas. During the open state, nutrient input from the sea is expected to be low, except when the open state coincides with an upwelling event at sea (i.e. when naturally, high nutrient bottom waters in the ocean enter surface waters), as has been observed in the adjacent Palmiet Estuary (Taljaard 1987).

B.2.2 Responses to climate change scenarios

The Botvlei is a shallow, well-mixed estuary with the water column generally being well-oxygenated. The dissolved oxygen regimes for the different states will be determined by the salinity regime and the season (temperature). Even though nutrient concentrations can be very high, it is not expected for dissolved oxygen to often drop below 4 mg/ℓ in the main, exposed basins. However, in sheltered areas dense algal blooms can result in significant diurnal fluctuation (from supersaturation during the day to hypoxia during the night), and hypoxia (anoxia) during the die-off of these blooms (if not flushed from the system).

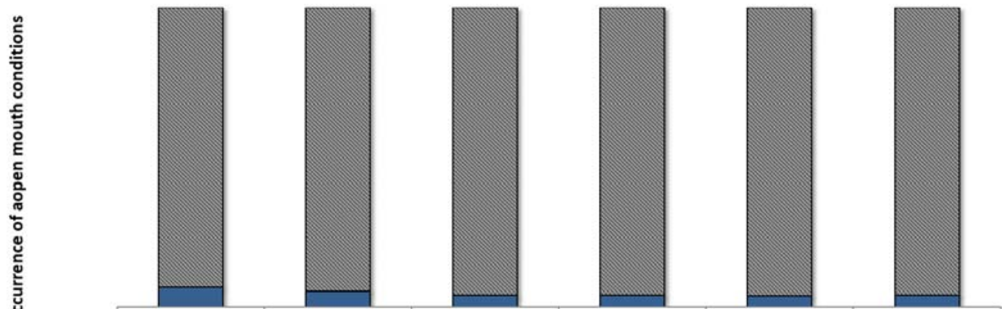
The Bot/Kleinmond responds to river flow in all its variability. Breaching is dependent on the total inflow and flood events, while the duration of the open period responds to the breaching level and occurrence of higher flow events post breaching. Predicted changes in hydrodynamic functioning, marine connectivity average water level and salinity are captured in the overall occurrence of different abiotic states in the Bot/Kleinmond estuary are summarised in Figure B.3. The approach followed here did not focus on connectivity through the Kleinmond mouth but assumes that State 3 and State is representative of periods that the system will have an outflow through Kleinmond.



	Natural	Present	Sc1: RCP 4.5 Mid	Sc 2: RCP 4.5 Far	Sc 3: RCP 8.5 Mid	Sc 4: RCP 8.5 Far
State 1: Closed hypersaline	0.2	0.7	0.7	0.7	0.2	0.2
State 2: Closed Marine	41.7	34.3	26.9	27.0	25.2	28.2
State 3: Closed Brackish	21.9	20.2	18.6	18.9	18.6	21.3
State 4: Closed Fresh	29.5	39.5	49.8	49.4	52.3	46.2
State 5: Open Marine	6.7	5.2	4.0	3.9	3.7	4.0

Figure B.3: Bot/Kleinmond; Occurrence of different abiotic states under different scenarios

The Bot/Kleinmond has relatively low connectivity to the sea (Figure B.4 and Table B.7). However, the open state represents a very important aspect of the hydrodynamics cycle that serves as resetting events and facilitates the systems distinct "boom-and-bust" cycles. Mouth conditions show a decline from natural and present, with Scenarios 2 and 3 being the most severe. Most shifts in marine connectivity are associated with June, July, and September. Less connectivity is also predicted for November.



	Natural	Present	Sc1: RCP 4.5 Mid	Sc 2: RCP 4.5 Far	Sc 3: RCP 8.5 Mid	Sc 4: RCP 8.5 Far
Closed	93.3	94.8	96.0	96.1	96.3	96.0
Open	6.7	5.2	4.0	3.9	3.7	4.0

Figure B.4: Bot/Kleinmond: Overall occurrence of open mouth conditions (expressed as % open) under different scenarios

Average water levels under the future scenarios are slightly higher than the present, mostly in the period June to September (Figure 4.6 and Table 4.7). The most notable shifts are associated with Scenario 3. However, it should be noted that this increase in average water levels is the result of an increase in the occurrence of the closed states, which off-set the loss of higher water levels under natural conditions. Predicted water level changes are Table B.8.

Table B.7: Bot/Kleinmond: Estimated percentage time estuary is connected to the sea under different scenarios (darker colours indicate high connectivity and light colours low connectivity)

	PRESENT					SCENARIO 1					SCENARIO 2					SCENARIO 3					SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (70 YEAR SIMULATION PERIOD)																									
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
June	16	16	16	16	16	10	10	10	10	10	9	9	9	9	9	9	9	9	9	9	10	10	10	10	10
July	13	13	13	13	13	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	10	10	10	10	10
August	20	20	20	20	20	17	17	17	17	17	19	19	19	19	19	17	17	17	17	17	19	19	19	19	19
September	7	7	7	7	7	7	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PERCENTILE DISTRIBUTION (70 YEAR SIMULATION PERIOD)																									
99%ile	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
95%ile	O	O	O	O	O	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
90%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
80%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
70%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
60%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
50%ile (median)	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
40%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
30%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
20%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
10%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
1%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C

Table B.8: Bot/Kleinmond: Predicted water level (m) under Present State and Future Climate Change Scenarios

	PRESENT					SCENARIO 1					SCENARIO 2					SCENARIO 3					SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (70 YEAR SIMULATION PERIOD)																									
January	1.8	1.8	1.8	1.8	1.8	2.0	2.0	2.0	1.9	2.0	2.0	2.0	2.0	1.9	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9
February	1.8	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9
March	1.8	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9
April	1.8	1.8	1.8	1.8	1.8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
May	1.8	1.8	1.8	1.8	1.8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9
June	1.7	1.7	1.7	1.7	1.7	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.8	1.8	1.8
July	1.7	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.8	1.8	1.8
August	1.6	1.6	1.6	1.6	1.6	1.8	1.8	1.8	1.8	1.8	1.7	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.7	1.7	1.7	1.7	1.7
September	1.8	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9
October	1.9	1.9	1.9	1.9	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
November	1.8	1.8	1.8	1.8	1.8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9
December	1.8	1.8	1.8	1.8	1.8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9
PERCENTILE DISTRIBUTION (70 YEAR SIMULATION PERIOD)																									
99%ile	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
95%ile	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
90%ile	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
80%ile	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
70%ile	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
60%ile	2.0	2.0	2.0	2.0	2.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
50%ile (median)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.5	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
40%ile	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
30%ile	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0
20%ile	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10%ile	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1%ile	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

Salinity regimes under Scenario 1 to 4 likely will lead to a slight improvement from the present as a result of the dominance of the closed states. Scenario 1 and 3 represents the most shift in this regard. In most scenarios, the decrease in the occurrence of other states was offset by an increase in State 4: Closed Fresh conditions. A summary of the results is presented in Table B.9.

Table B.9: Bot/Kleinmond: Predicted salinity under Present State and Future Climate Change Scenarios

	PRESENT					SCENARIO 1					SCENARIO 2					SCENARIO 3					SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (70 YEAR SIMULATION PERIOD)																									
January	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
February	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
March	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
April	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
May	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
June	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7
July	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3
August	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4
September	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9
October	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6
November	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4
December	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
PERCENTILE DISTRIBUTION (70 YEAR SIMULATION PERIOD)																									
99%ile	25	35	35	30	15	25	35	35	30	15	25	35	35	30	15	25	35	35	30	15	25	35	35	30	15
95%ile	25	35	35	30	15	25	35	35	30	15	25	35	35	30	15	25	35	35	30	15	25	35	35	30	15
90%ile	25	35	35	30	15	25	35	35	30	15	25	35	35	30	15	25	35	35	30	15	25	35	35	30	15
80%ile	25	35	35	30	15	25	35	35	30	15	25	35	35	30	15	25	35	35	30	15	25	35	35	30	15
70%ile	25	35	35	30	10	10	25	35	10	10	10	25	35	10	10	10	20	20	10	10	10	25	35	10	10
60%ile	10	25	35	10	10	10	20	20	10	10	10	20	20	10	10	10	20	20	10	10	10	20	20	10	10
50%ile (median)	10	20	20	10	10	10	20	20	5	10	10	20	20	5	10	1	5	5	5	5	10	20	20	10	10
40%ile	10	20	20	5	10	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5
30%ile	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5
20%ile	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5
10%ile	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5
1%ile	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5	1	5	5	5	5

Predicted changes in seasonal and percentile distribution of water quality under present and future Climate Change scenarios are provided in Table B.10. Present water quality in the Bot/Kleinmond has been significantly modified by anthropogenic pollution inputs, in this case mostly wastewater and agricultural return flow entering the Bot systems (Zones A to C). With a slight increase in State 4 (Closed, fresh) under the future Climate Change Scenarios – when relatively higher (polluted) inflows enter a closed system – a slight further deterioration in water quality can be expected, especially in the Bot system (Zones A to C).

Table B.10: Bot/Kleinmond: Predicted water quality under Present State and Future Climate Change Scenarios

	BOT/KLEINMOND: PRESENT					BOT/KLEINMOND: SCENARIO 1					BOT/KLEINMOND: SCENARIO 2					BOT/KLEINMOND: SCENARIO 3					BOT/KLEINMOND: SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																									
January	5	5	3	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	3	3	3
February	5	5	3	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	3	3	3
March	5	5	3	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	3	3	3
April	5	5	3	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3
May	5	5	3	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3
June	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3
July	5	5	3	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3
August	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3
September	5	5	3	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3
October	5	5	3	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	3	3	3
November	5	5	3	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3
December	5	5	3	3	3	5	5	4	3	3	5	5	4	3	3	5	5	4	3	3	5	5	3	3	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																									
95%ile	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4
90%ile	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4
80%ile	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4
70%ile	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4
60%ile	4	4	4	4	2	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4	6	6	4	4	4
50%ile (median)	4	4	3	2	2	5	5	4	4	3	4	4	4	4	2	6	6	4	4	4	4	4	4	2	2
40%ile	4	4	3	2	2	4	4	3	2	2	4	4	3	2	2	4	4	3	2	2	4	4	3	2	2
30%ile	4	4	3	2	2	4	4	3	2	2	4	4	3	2	2	4	4	3	2	2	4	4	3	2	2
20%ile	4	4	3	2	2	4	4	3	2	2	4	4	3	2	2	4	4	3	2	2	4	4	3	2	2
10%ile	4	4	3	2	2	4	4	3	2	2	4	4	3	2	2	4	4	3	2	2	4	4	3	2	2

B.3 Biotic Responses

B.3.1 Microalgae

The conceptual model for microagal characteristics under different abiotic scenarios is illustrated in Figure B.5, while the microagal characteristics associated with different zone are summarised in Table B.11.

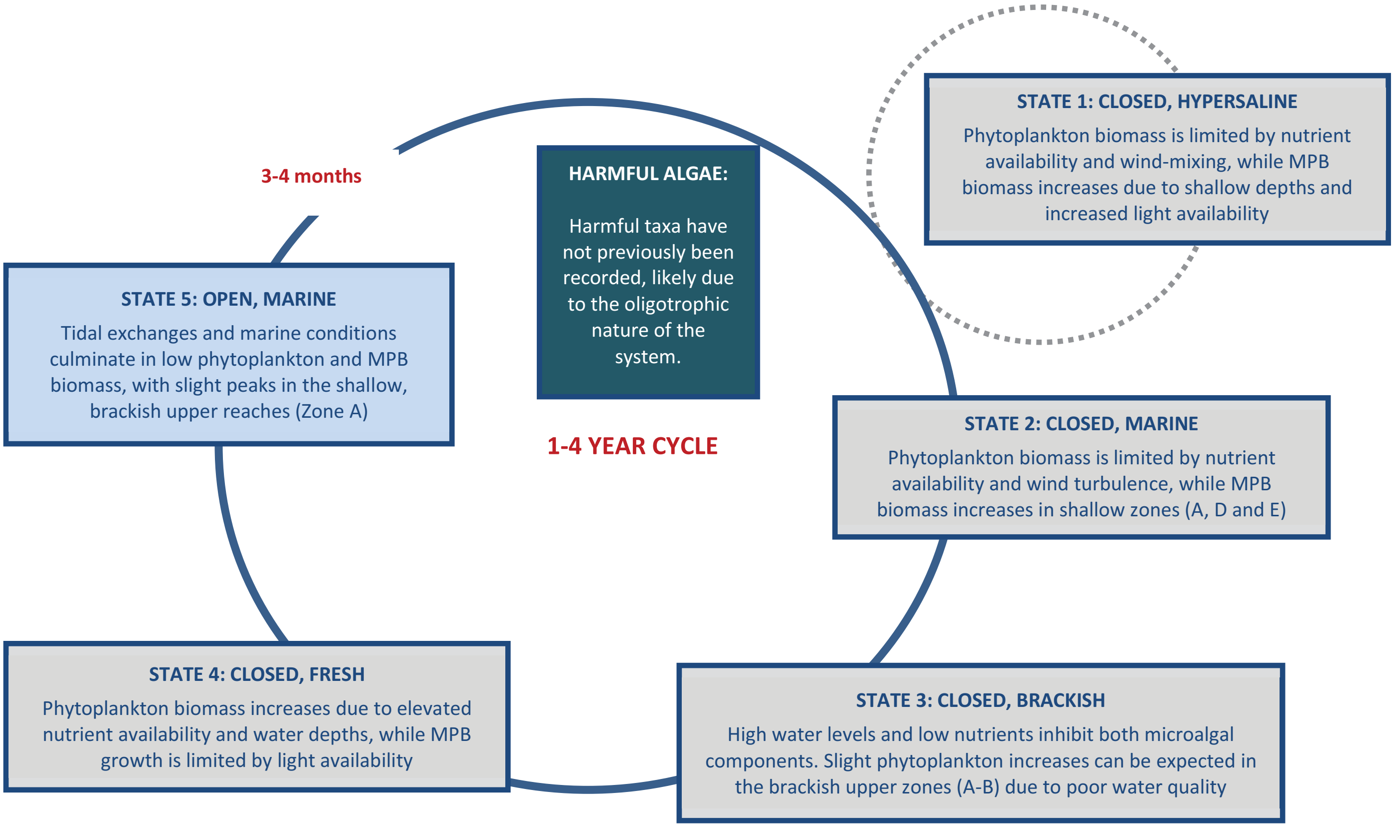


Figure B.5 Bot/Kleinmond: Microalgae Conceptual model

Phytoplankton biomass is highest during periods of mouth closure and increased nutrient availability. Despite a lack of available data, phytoplankton biomass would likely increase (~Fair: ≥ 5 but <20 µg/ℓ) throughout the system during nutrient-rich freshwater conditions associated with closed mouth conditions (State 4). The most prominent phytoplankton classes are likely to comprise freshwater taxa belonging to Bacillariophyceae (diatoms), Chlorophyceae (greens) and Cyanophyceae (cyanobacteria). Benthic microalgae biomass is expected to be predominantly low (~Good: < 50 mg/m^2) during all the prescribed states due to high turbulence induced by wind-mixing, with slight increases (~Fair: ≥ 50 but < 100 mg/m^2) during low water levels and increased nutrient remineralisation processes (~State 1); particularly in the shallower zones (A, D and E). The presence of harmful algal species is unlikely given the largely oligotrophic state of the microalgae communities.

Table B.11: Bot/Kleinmond: Key microalgal characteristics associated with various states

STATE	PARAMETER	ZONE A	ZONE B	ZONE C	ZONE D	ZONE E
State 1: Closed, hypersaline 1	Phytoplankton:				-	
	Benthic microalgae:				-	
	Harmful algae:				-	
State 2: Closed, marine	Phytoplankton:					
	Benthic microalgae:					
	Harmful algae:					
State 3: Closed, brackish	Phytoplankton:					
	Benthic microalgae:					
	Harmful algae:					
State 4: Closed, fresh	Phytoplankton:					
	Benthic microalgae:					
	Harmful algae:					
State 5: Open, marine	Phytoplankton:				-	
	Benthic microalgae:				-	
	Harmful algae:				-	

Confidence levels: Phytoplankton – Low; Benthic microalgae – Low; Harmful algae – Low

A summary of the key responses in microalgae under the Present State and Future Climate Change scenarios are summarized in Table B.12. Predicted changes in seasonal and percentile distribution of microalgae under present and future Climate Change scenarios are provided in Tables B.13 to B.15.

Table B.12: Bot/Kleinmond: Predicted change in Microalgae under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	At present, the microalgal communities are representative of a predominantly oligotrophic environment, with marginal deviations observed during extreme conditions (e.g. elevated benthic microalgal growth during hypersaline and low water level conditions).
1-4	The predicted shift towards the increased frequency of closed mouth conditions and reduced salinity is expected to increase phytoplankton growth. Contrastingly, the growth of benthic microalgae is expected to be hindered by increased water depths (i.e. less suitable habitat). However, wind-induced turbulence, particularly in Zone B and C, is expected to limit phytoplankton biomass and the persistence of any HAB species. Thus, the increased temperature predicted for Scenario 4 is expected to result in only marginal increases in microalgal growth.

Table B.13: Bot/Kleinmond: Predicted Phytoplankton responses under Present State and Future Climate Change Scenarios

BOT/KLEINMOND: PRESENT	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (SIMULATION PERIOD)					
January	2	2	2	2	2
February	2	2	2	2	2
March	2	2	2	2	2
April	2	2	2	2	2
May	2	2	2	2	2
June	2	2	2	2	2
July	2	2	2	2	2
August	2	2	2	2	2
September	2	2	2	2	2
October	2	2	2	2	2
November	2	2	2	2	2
December	2	2	2	2	2
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)					
95%ile	3	3	3	3	3
90%ile	3	3	3	3	3
80%ile	3	3	3	3	3
70%ile	3	3	3	3	3
60%ile	3	3	2	3	1
50%ile (median)	3	3	2	1	1
40%ile	3	3	2	1	1
30%ile	1	1	1	1	1
20%ile	1	1	1	1	1
10%ile	1	1	1	1	1

BOT/KLEINMOND: SCENARIO 1	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (SIMULATION PERIOD)					
January	2	2	2	2	2
February	2	2	2	2	2
March	2	2	2	2	2
April	2	2	2	2	2
May	2	2	2	2	2
June	2	2	2	2	2
July	2	2	2	2	2
August	3	2	2	2	2
September	3	2	2	2	2
October	2	2	2	2	2
November	2	2	2	2	2
December	2	2	2	2	2
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)					
95%ile	3	3	3	3	3
90%ile	3	3	3	3	3
80%ile	3	3	3	3	3
70%ile	3	3	3	3	3
60%ile	3	3	3	3	3
50%ile (median)	3	3	3	3	2
40%ile	3	3	2	1	1
30%ile	3	1	1	1	1
20%ile	1	1	1	1	1
10%ile	1	1	1	1	1

BOT/KLEINMOND: SCENARIO 2	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (SIMULATION PERIOD)					
January	2	2	2	2	2
February	2	2	2	2	2
March	2	2	2	2	2
April	2	2	2	2	2
May	2	2	2	2	2
June	2	2	2	2	2
July	2	2	2	2	2
August	3	2	2	2	2
September	2	2	2	2	2
October	2	2	2	2	2
November	2	2	2	2	2
December	2	2	2	2	2
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)					
95%ile	3	3	3	3	3
90%ile	3	3	3	3	3
80%ile	3	3	3	3	3
70%ile	3	3	3	3	3
60%ile	3	3	3	3	3
50%ile (median)	3	3	2	3	1
40%ile	3	3	2	1	1
30%ile	3	1	1	1	1
20%ile	1	1	1	1	1
10%ile	1	1	1	1	1

BOT/KLEINMOND: SCENARIO 3	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (SIMULATION PERIOD)					
January	2	2	2	2	2
February	2	2	2	2	2
March	2	2	2	2	2
April	2	2	2	2	2
May	3	2	2	2	2
June	3	2	2	2	2
July	2	2	2	2	2
August	3	2	2	2	2
September	3	2	2	2	2
October	2	2	2	2	2
November	2	2	2	2	2
December	2	2	2	2	2
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)					
95%ile	3	3	3	3	3
90%ile	3	3	3	3	3
80%ile	3	3	3	3	3
70%ile	3	3	3	3	3
60%ile	3	3	3	3	3
50%ile (median)	3	3	3	3	3
40%ile	3	3	2	1	1
30%ile	3	3	2	1	1
20%ile	1	1	1	1	1
10%ile	1	1	1	1	1

BOT/KLEINMOND: SCENARIO 4	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (SIMULATION PERIOD)					
January	2	2	2	2	2
February	2	2	2	2	2
March	2	2	2	2	2
April	2	2	2	2	2
May	2	2	2	2	2
June	2	2	2	2	2
July	2	2	2	2	2
August	2	2	2	2	2
September	2	2	2	2	2
October	2	2	2	2	2
November	2	2	2	2	2
December	2	2	2	2	2
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)					
95%ile	3	3	3	3	3
90%ile	3	3	3	3	3
80%ile	3	3	3	3	3
70%ile	3	3	3	3	3
60%ile	3	3	3	3	3
50%ile (median)	3	3	3	1	1
40%ile	3	3	3	1	1
30%ile	3	2	1	1	1
20%ile	1	1	1	1	1
10%ile	1	1	1	1	1

Table B.14: Bot/Kleinmond: Predicted Benthic microalgae responses under Present State and Future Climate Change Scenarios

	BOT/KLEINMOND: PRESENT					BOT/KLEINMOND: SCENARIO 1					BOT/KLEINMOND: SCENARIO 2					BOT/KLEINMOND: SCENARIO 3					BOT/KLEINMOND: SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																									
January	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	2	2	2	2
February	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	2	2	2	2
March	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	2	2	2	2
April	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	2	2	2	2
May	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	1	2	2	2	2	2
June	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	1	2	2	2	1	2
July	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	2	2	2	2
August	2	1	1	2	2	2	1	1	2	1	2	1	1	2	1	2	1	1	2	1	2	2	2	1	2
September	2	1	1	2	2	2	1	1	2	1	2	1	1	2	2	2	1	1	1	1	2	2	2	1	2
October	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	2	2	2	2
November	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	2	2	2	2
December	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	2	2	2	2
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																									
95%ile	3	2	2	3	3	3	2	2	3	3	3	2	2	3	3	3	2	2	3	3	3	3	3	3	3
90%ile	3	2	2	3	3	3	2	2	3	3	3	2	2	3	3	3	2	2	3	3	3	3	3	3	3
80%ile	3	2	2	3	3	3	2	2	3	3	3	2	2	3	3	3	2	2	3	3	3	3	3	3	3
70%ile	3	2	2	3	3	3	1	1	1	1	3	1	1	1	1	1	1	1	1	1	3	1	1	1	1
60%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
50%ile (median)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
40%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
30%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table B.15: Bot/Kleinmond: Predicted Harmful algae responses under Present State and Future Climate Change Scenarios

	BOT/KLEINMOND: PRESENT					BOT/KLEINMOND: SCENARIO 1					BOT/KLEINMOND: SCENARIO 2					BOT/KLEINMOND: SCENARIO 3					BOT/KLEINMOND: SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																									
January	2	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
February	2	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
March	2	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
April	2	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
May	2	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
June	2	2	1	1	1	2	2	1	2	1	2	2	1	2	1	2	2	2	2	2	2	2	2	1	1
July	2	2	1	1	1	2	2	1	2	1	2	2	1	2	1	2	2	1	2	1	2	2	2	1	1
August	2	2	1	1	1	2	2	1	2	1	2	2	1	1	1	2	2	1	2	1	2	2	2	1	1
September	2	2	1	1	1	2	2	1	2	1	2	2	1	2	1	2	2	2	2	2	2	2	2	1	1
October	2	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
November	2	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
December	2	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																									
95%ile	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2
90%ile	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2
80%ile	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2
70%ile	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2
60%ile	2	2	1	2	1	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2	3	3	2	2	2
50%ile (median)	2	2	1	1	1	3	3	2	2	2	2	2	1	2	1	3	3	2	2	2	2	2	2	1	1
40%ile	2	2	1	1	1	2	2	1	1	1	2	2	1	1	1	2	2	1	1	1	2	2	2	1	1
30%ile	1	1	1	1	1	2	1	1	1	1	2	1	1	1	1	2	2	1	1	1	2	2	1	1	1
20%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

B.3.2 Macrophytes

Water level, mouth state, sedimentation, and duration of closure influence macrophyte habitat in the Bot/Kleinmond system. Below 1.3 MSL salt marsh grows and replenishes seed sediment reserves (Van Niekerk 2010). Above 1.5 MSL and water retention time of more than 6 months, submerged macrophytes expand but they can also be influenced by turbidity. They are present during the open mouth state, but tidal movement restricts their growth to quiet backwater areas. Reed growth is seasonal and responds to sediment input. The pioneer seagrass *Halophila ovalis* can occur in monospecific stands in shallower water, but once the water level rises it is easily out competed by species that are physically more robust. This species also occurs at salinity levels of 20 to 35. Low salinity (< 20) is important for seed germination and re-establishment of both submerged and salt marsh plants. Increased nutrient input has a negative effect on submerged macrophytes through a reduction in light availability due to increased epiphytic growth, macroalgal and phytoplankton blooms.

Low water level (2004): Submerged macrophyte growth limited, salt marsh develops in the upper reaches

High water level (1.97 MSL) (7 Aug 2005): Salt marsh flooded, submerged macrophyte growth at < 2 m depth

The macrophyte conceptual model for Bot/Kleinmond is presented in Figure B.6.

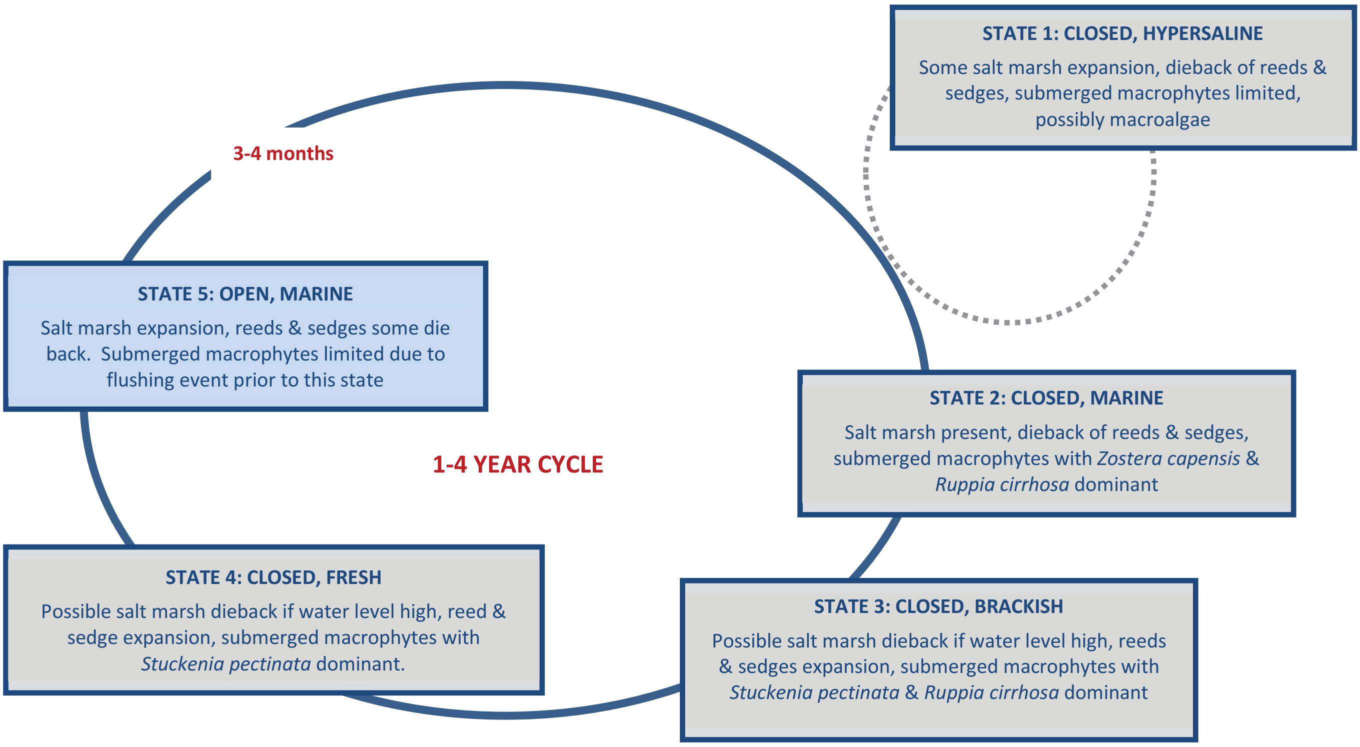


Figure B.6: Bot/Kleinmond: Macrophyte Conceptual model

Predicted changes in response to different scenarios are summarised in Table B.16.

Table B.16: Bot/Kleinmond: Predicted change in macrophytes under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Supratidal salt marsh = 117.8 ha, Salt marsh = 137.8 ha, Submerged = 46.1 ha, Reeds and sedges = 301.56, Open water = 1072.8 ha. Macrophytes change in response to mouth condition; 3 to 4 months open; 1 to 4 yrs closed.
1	**Drier (7.1%) therefore longer mouth closure and salinity increase; mouth closed more often and closed fresh mostly increases.** Longer mouth closure will result in an increase in submerged macrophytes; reeds will also increase up to a level where it becomes too deep, salt marsh decreases as habitat is flooded. The decrease in the score compared to present is in response to the increase in nutrients that will promote macroalgal growth.
2	**Drier (8.2%) therefore longer mouth closure and salinity increase; closed marine and closed fresh increase most; most water level increase between June and September** Longer mouth closure will result in an increase in submerged macrophytes; reeds will also increase up to a level where it becomes too deep, highest water level occurs over the natural die back period but also at the start of the regrowth period. If water level is too high reeds won't grow back. Salt marsh decreases as this habitat is flooded. Increase in nutrients will promote macroalgal growth.
3	**Drier (12%) therefore longer mouth closure and salinity increase; closed marine and closed fresh increases most; most water level increase between June and September** Longer mouth closure will result in an increase in submerged macrophytes; reeds will also increase up to a level where it becomes too deep, highest water level occurs over the natural die back period but also at the start of the regrowth period. If water level is too high reeds won't grow back. Salt marsh decreases as this habitat is flooded. Increase in nutrients will promote macroalgal growth.
4	**Drier (15.1%) therefore longer mouth closure and salinity increase; closed marine and closed fresh increases most** Longer mouth closure will result in an increase in submerged macrophytes; reeds will also increase up to a level where it becomes too deep, salt marsh decreases as this habitat is flooded. Increase in nutrients will promote macroalgal growth.

B.3.3 Fish

A total of 41 fish species from 24 families have been recorded from the Bot (Bennett 1985, 1989; Bennett et al. 1985; Branch et al. 1985; Lamberth unpublished data in Van Niekerk et al. 2010). Nineteen (46%) of these are entirely dependent on estuaries to complete their lifecycle. Eight of these breed in estuaries and include the estuarine round-herring *Gilchristella aestuaria*, Bot River klipvis *Clinus spatulatus*, Cape halfbeak *Hyporhamphus capensis*, Cape silverside *Atherina breviceps*, Knysna sand-goby *Psammogobius knysnaensis*, three *Caffrogobius* species and pipefish *Syngnathus temminckii*. Seven species, dusky kob *Argyrosomus japonicus*, white steenbras *Lithognathus lithognathus*, leervis *Lichia amia*, Cape moony *Monodactylus falciformis*, flathead mullet *Mugil cephalus*, freshwater mullet *Myxus capensis* and Cape stumpnose *Rhabdosargus holubi*, are dependent on estuaries as nursery areas for at least their first year of life. A further three, African mottled eel *Anguilla bengalensis*, Madagascan mottled eel *A. marmorata* and longfin eel *A. mossambica* are obligate catadromous and use estuaries as transit routes between the marine and freshwater environment. In addition, *Mugil cephalus* and *Myxus capensis* may be regarded as facultative catadromous species. Ten (24%) of the fish species, including harder *Liza richardsonii*, groovy mullet *Liza dumerilii*, elf *Pomatomus saltatrix* and white stumpnose *Rhabdosargus globiceps*, are at least partially dependent on estuaries. Most of the 12 remaining species are marine species, e.g. piggy *Pomadasys olivaceum* and wildeperd *Diplodus cervinus*, which occur in, but are not dependent on estuaries. Four species, the indigenous Cape galaxias zebratus and introduced carp *Cyprinus carpio*, largemouth bass *Micropterus salmoides* and Mozambique tilapia *Oreochromis mossambicus*, are alien euryhaline freshwater species whose penetration into estuaries is determined by salinity tolerance.

Species that breed in estuaries and/or estuarine residents comprise 20% of the Bot fish fauna. Entirely estuarine dependent species comprise 46% of the Bot fish fauna, while partially estuarine dependent species comprise 20% of the Bot fish fauna. Non-estuary dependent marine species comprise a relatively low proportion (20%) of the fish species recorded and most, e.g. gurnard *Chelidonichthys capensis* and anchovy *Engraulis japonicus* can be construed as rare vagrants which seldom enter estuaries, their occurrence in the temporarily open/closed Bot largely a function of their chance proximity to the mouth when it was open. Based on their distributional ranges given by Smith and Heemstra (1986), 20 (49%) of the fish recorded in the Bot are southern African endemics including the Botriver klipvis *Clinus spatulatus* which has an extremely limited range being confined to the Bot and nearby Bot/Kleinmond. The fish conceptual model for Bot/Kleinmond is presented in Figure B.7.

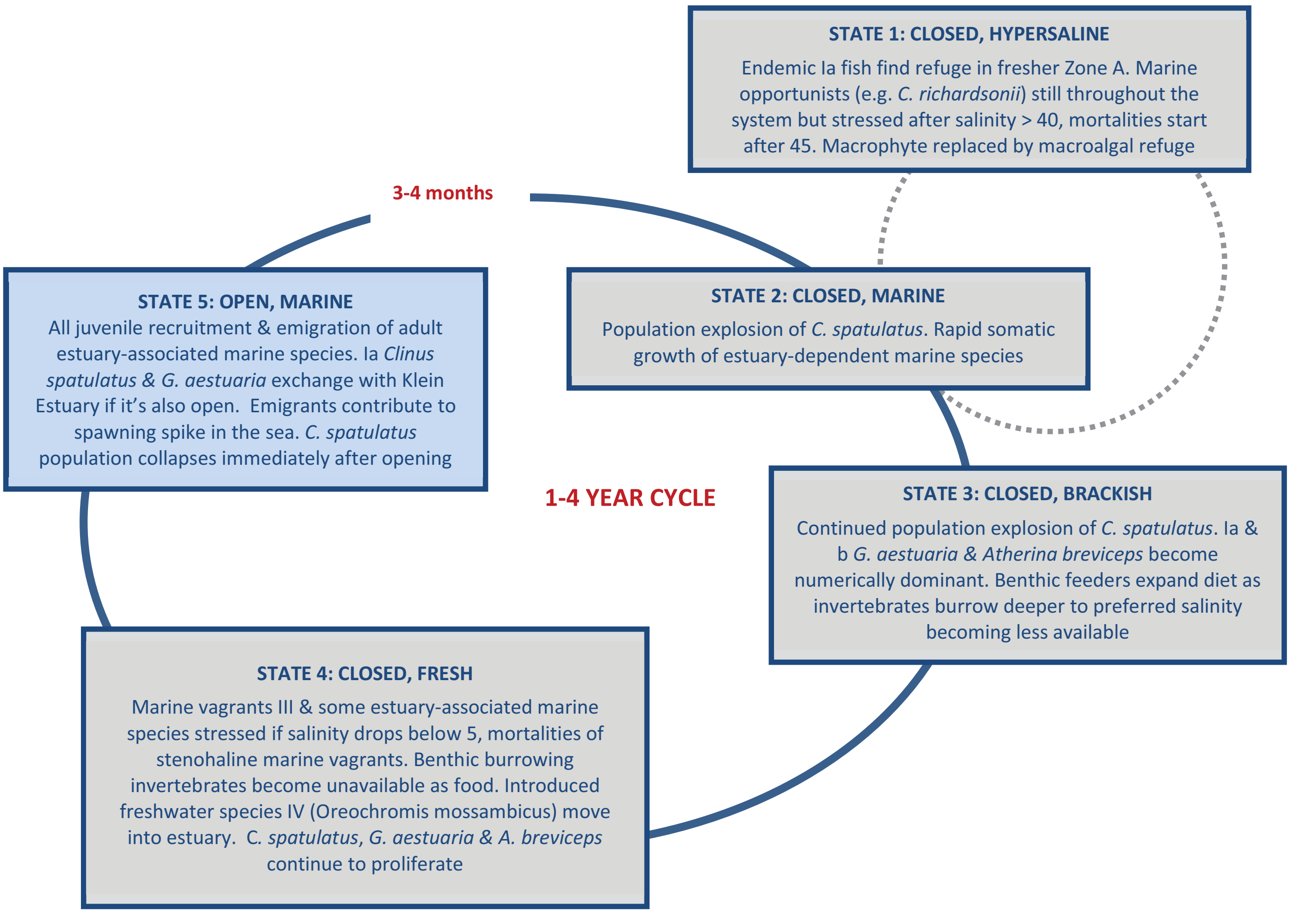


Figure B.7 Bot/Kleinmond: Fish Conceptual model

Predicted changes in response to different scenarios are summarised in Table B.17.

Table B.17: Bot/Kleinmond: Predicted change in fish under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Species Richness: Decline in survival of recruited estuary-dependent and marine-migrant species. Four alien & translocated species. Reduction in recruitment and emigration due to increased mouth closure. Biomass: Abundance of IIa & b unchanged but 90% decline in that of estuary-dependent species. Arrival of four freshwater alien/translocated species. Much of this aggravated by illegal gillnet fishery and difficult to disaggregate. Increased mouth closure increases chance of fish being caught in the estuary before maturing and being able to return to spawn in the sea Community composition: Community dominated by planktonic filter/selective feeders, fodder fish as opposed to piscivorous and large benthic feeders under reference.

SCENARIO	SUMMARY OF CHANGES
1-3	Closed fresher high-water levels favour estuarine residents *G. aestuaria* and *A. breviceps* but also *Clinus spatulatus* which experiences population booms during closure, bust on opening. Submerged macrophytes increase during closure which also favours these species. Limited recruitment via over-wash and/or via Kleinmond but populations of marine opportunists and obligate estuary-dependent species comprise mostly one or two cohorts that were recruited during the previous opening. Synchronised mouth opening events and genetic exchange between Bot and Klein estuary-residents becomes more limited. Lower salinity after prolonged closure sees invasion of translocated *Oreochromis mossambicus* (or *O. niloticus* hybrid) and alien fish, e.g. *C. carpio* into the main water body from upstream. Fresh conditions throughout may see some stress and few mortalities in the less euryhaline species. Alternatively, hypersalinity resulting from drought and low flow during closure may see fish kills from osmotic stress once salinity exceeds 45.
4	Hypersalinity resulting from drought and low flow during closure more likely and may see fish kills from osmotic stress once salinity exceeds 45. Endemic Ia fish find refuge in fresher Zone A. Marine opportunists (e.g. *C. richardsonii*) still throughout the system but stressed after salinity > 40, mortalities start after 45. Macrophyte replaced by macroalgal refuge. Benthic burrowing invertebrates nearer

C. KLEIN

C.1.1 Predicted Climate Change Scenarios

Predicted climate change scenarios for RCP 4.5 and 8.5 under mid and far future scenarios relevant to the Klein, are presented in Tables C.1 to C.3 for precipitation in the catchment, precipitation in EFZ and ambient atmospheric temperature, respectively. A summary of broad measures of hydrological changes, as reported by Cullis et al. (2015), is provided in Table C.4.

Table C.1: Klein: Predicted change in precipitation in catchment for RCP 4.5 and 8.5 under mid- and far-future scenarios

CATCHMENT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	15	-21	-17	-36	-18	-15	-24	-10	-2	39	-20	-11
RCP 4.5 Far	45	-15	-18	-8	4	-20	-24	4	-18	28	-31	3
RCP 8.5 Mid	24	-20	-4	-16	-16	-18	-23	-21	-7	-11	-13	-5
RCP 8.5 Far	22	-34	-11	-26	-23	-23	-40	-17	-24	-22	-31	-11

Table C.2: Klein: Predicted change in precipitation in EFZ for RCP 4.5 and 8.5 under mid- and far-future scenarios

ESTUARY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	5	-22	-9	-40	-15	-12	-20	-13	-4	26	-19	-12
RCP 4.5 Far	33	-20	1	-19	7	-19	-22	5	-22	24	-26	5
RCP 8.5 Mid	9	-16	11	-24	-19	-17	-17	-22	-3	-14	-12	-10
RCP 8.5 Far	6	-38	-12	-35	-20	-26	-40	-19	-25	-23	-29	-14

Table C.3: Klein: Predicted increase in the ambient atmospheric temperature (°C) for RCP 4.5 and 8.5 under mid- and far-future scenarios

TAve	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	1.5	1.3	1.3	2.0	1.5	1.9	1.5	1.3	1.8	1.5	1.4	1.8
RCP 4.5 Far	1.7	1.7	1.7	2.3	1.5	1.9	2.2	2.5	2.5	2.2	1.8	2.4
RCP 8.5 Mid	1.6	1.3	1.5	2.2	1.9	2.4	2.1	2.0	2.5	2.6	2.2	2.1
RCP 8.5 Far	3.7	3.4	3.3	4.0	4.6	4.1	4.0	3.7	4.1	4.3	4.1	3.8
Tmax	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	0.9	1.0	1.2	2.4	1.6	2.1	1.6	1.1	1.9	1.3	1.4	1.9
RCP 4.5 Far	1.1	1.4	1.7	2.7	1.8	1.9	2.5	2.6	2.8	2.0	2.0	2.4
RCP 8.5 Mid	0.9	1.0	1.4	2.3	2.1	2.6	2.4	1.9	2.8	2.7	2.2	1.8
RCP 8.5 Far	3.1	2.9	2.8	4.1	4.7	4.2	4.3	3.8	4.2	4.5	4.2	3.5
Tmin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	2.1	1.6	1.3	1.6	1.4	1.6	1.4	1.5	1.7	1.7	1.4	1.7
RCP 4.5 Far	2.4	2.1	1.6	1.9	1.2	1.9	1.9	2.4	2.3	2.4	1.7	2.4
RCP 8.5 Mid	2.3	1.7	1.6	2.1	1.8	2.3	1.8	2.0	2.1	2.5	2.1	2.3
RCP 8.5 Far	4.4	3.8	3.9	3.8	4.4	4.0	3.6	3.5	3.9	4.1	4.0	4.1

Table C.4: Klein: Summary of broad measures of hydrological change (as reported by Cullis et al. 2015)

PARAMETER	PERCENTAGE CHANGE
Median Flows	-10%
Q 1 (low flows)	-10%
Q 3 (Floods)	-10%
Min	-20%
Max	-5%

Table C.5 provide a summary of potential change in runoff under RCP 4.5 and 8.5 scenarios for mid and far future conditions.

Table C.5: Klein: Summary of potential change in the runoff under RCP 4.5 and 8.5 scenarios for mid and far future conditions

SCENARIO NAME	DESCRIPTION	MAR (x 10^6 m^3)	PERCENTAGE REMAINING
Natural	Reference condition	53.41	
Present	Present	40.88	76.5
Scenario 1	RCP 4.5 Mid	41.07	76.9
Scenario 2	RCP 4.5 Far	41.82	78.3
Scenario 3	RCP 8.5 Mid	37.97	71.1
Scenario 4	RCP 8.5 Far	34.95	65.5

C.2 Abiotic Responses

C.2.1 Abiotic states and key characteristics

The characteristic abiotic states (and associated distinctive temporal patterns) for the Klein are illustrated conceptually in Figure C.1.

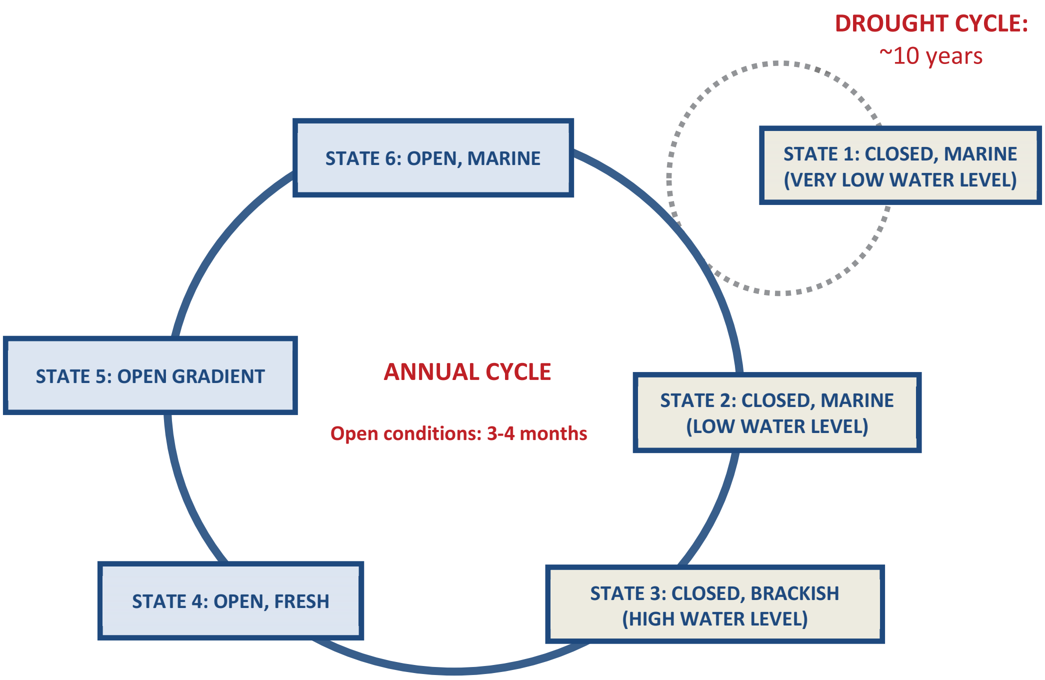


Figure C.1: Klein: Representative temporal patterns in the distribution of abiotic states (present)

On average the Klein Estuary breaches annually and remains open between 3 and 4 months after breaching, with a minimum period of 18 days and a maximum open period of 12.5 months. More than one breaching is possible in a year (but not likely). The estuary remains closed for about 7 months of the year on average. The highest frequency of breaching occurs between June and September, with a peak towards early spring (Anchor 2015).

During droughts, the estuary can remain closed for longer than a year. The longest period of closure on record was 25 months (e.g. the 2010/11 drought). In addition, the estuary also remained closed for more than a year in 1990/91 and 2003/05 indicating that droughts occur at decadal scales.

Six abiotic states (Table C.6) have been identified in the Klein Estuary, with *State 1: Closed, marine (very low water level)* associated with drought conditions as reflected in water levels below 1.0 m MSL and the formation of hypersalinity (36-40) in the shallow upper reaches (Zone C) of the system. During *State 2: Closed, marine (low water level)* the mouth of the estuary is closed, with water levels below 1.6 m MSL. Salinity in the basin (Zone A to C) is greater than 30, and around 25 in riverine section (Zone D) near Stanford. In *State 3: Closed, brackish (high water level)* the mouth of the estuary is still closed, with the system at water levels greater than 1.6 m MSL. Salinity in the basin (Zone A to C) is between 15 and 20, while the riverine zone (D) is between 10 and 15. *State 4: Open, fresh* represents an open mouth state, with the system under tidal conditions. Salinity in the lower basin (Zone A) is around 25, in the main and upper basin (Zone B and C) around 15 to 10, while fresh (0-5) in the riverine zone (D). While in *State 5: Open, gradient* the system is subjected to tidal action and lower river inflow, resulting in salinity in the lower and main basin (Zone A to B) greater than 30, and around 25 and 10 in the upper basin (Zone C) and riverine zone (D), respectively. Under *State 6: Open, marine* the system is tidal with very little freshwater input. Salinity in the basin (Zone A to C) is greater than 30 and is around 20 in the riverine zone (D).

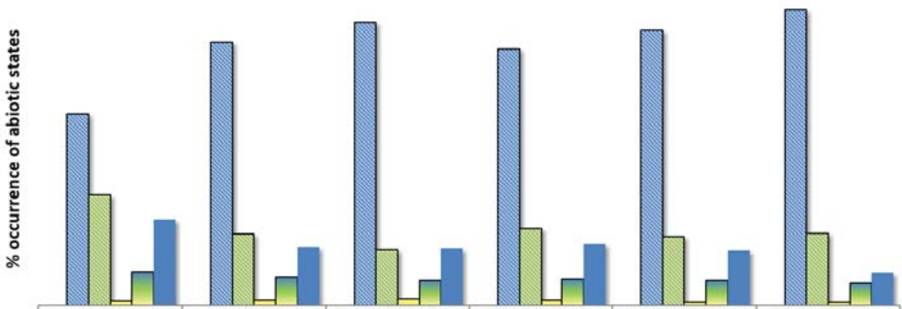
Table C.6: Klein: Key abiotic characteristics associated with various states

STATE	PARAMETER	ZONE A	ZONE B	ZONE C	ZONE D
State 1: Closed, marine (very low water level)	WL:	0.8-1.0			
	Salinity:	**35**	**35**	**40**	**25**
	Temp:	Summer: 23-28°C; Winter 12-17°C			
	WQ:	**SM (5)**	**SM (6)**	**SM (6)**	**SM (6)**
State 2: Closed, marine (low water level)	WL:	1.1-1.6			
	Salinity:	**30**	**30**	**30**	**25**
	Temp:	Summer: 23-28°°C; Winter 12-17°C			
	WQ:	**HM**	**SM (5)**	**SM (5)**	**SM (5)**
State 3: Closed, brackish (high water level)	WL:	1.6-2.6			
	Salinity:	20	20	20	15
	Temp:	Summer: 23-28°C; Winter 12-17°C			
	WQ:	**HM**	**HM**	**HM**	**SM (5)**
State 4: Open, fresh	WL:	-0.5 – 1.3 m (tide 30 cm)			
	Salinity:	25	15	10	0
	Temp:	Summer: 23-28°C; Winter 12-17°C			
	WQ:	**MM**	**HM**	**SM (5)**	**SM (5)**
State 5: Open, gradient	WL:	0-1.3 m (tide 30 cm)			
	Salinity:	35	35	25	10
	Temp:	Summer: 23-28°C; Winter 12-17°C			
	WQ:	**NN (2)**	**MM**	**HM**	**SM (5)**
State 6: Open, marine	WL:	0-1.3 m (tide 30 cm)			
	Salinity	35	35	35	20
	Temp:	Summer: 23-28°C; Winter 12-17°C			
	WQ:	**NN (2)**	**MM**	**MM**	**HM**

Extensive agricultural activities in the Klein catchment have increased nutrient loading in river inflow. Of note is a strong seasonal signal in the dissolved inorganic nitrogen (mostly NO_x-N) showing a distinct peak at the onset of the higher flow periods (late autumn/winter), associated with increased diffuse runoff from fertilised agricultural areas. Another major source of organic matter and inorganic nutrients to the Klein Estuary is the effluent discharge from the Stanford WWTW. As a result, water quality in the estuary deteriorated mostly associated with periods of low salinity (when river runoff and/or WWTW flows are higher) (Anchor Environmental Consulting 2015).

C.2.2 Responses to climate change scenarios

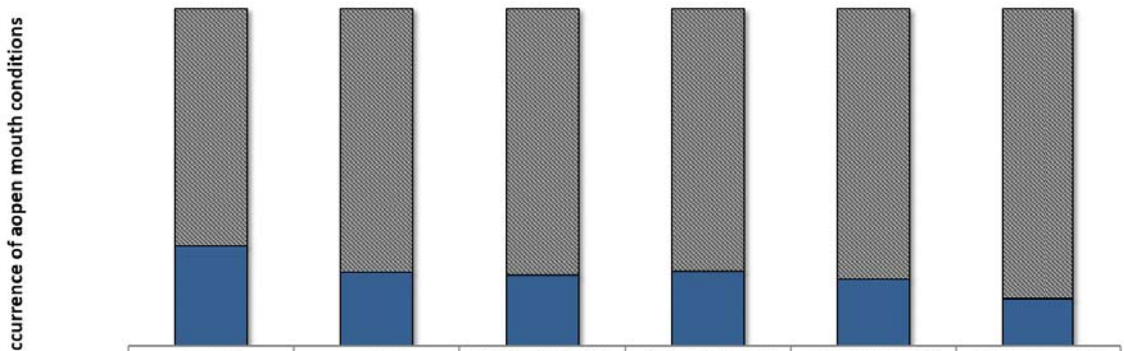
The Klein Estuary responds to river flow in all its variability. Breaching is dependent on the total inflow, while the duration of the open period responds to the breaching level, mouth position and occurrence of higher flow event post-breaching. Predicted changes in hydrodynamic functioning, average water level, salinity and marine connectivity are captured in the overall occurrence of different abiotic states in the Klein are summarised in Figure C.2.



	Natural	Present	Sc1: RCP 4.5 Mid	Sc 2: RCP 4.5 Far	Sc 3: RCP 8.5 Mid	Sc 4: RCP 8.5 Far
State 1: Closed Marine (LW level)	0.0	0.0	0.0	0.0	0.0	0.0
State 2: Closed Marine (HW level)	44.7	61.5	66.2	60.0	64.3	69.1
State 3: Closed Brackish	25.9	16.8	13.0	18.1	16.1	17.0
State 4: Open Fresh	1.2	1.3	1.6	1.3	0.8	0.8
State 5: Open gradient	7.9	6.7	6.0	6.3	6.0	5.4
State 6: Open marine	20.2	13.7	13.3	14.4	12.9	7.7

Figure C.2: Klein: Occurrence of different abiotic states under different scenarios

Mouth conditions showed limited sensitivity to the changes in river flow to the estuary (Figure C.3 and Table C.7). Under Scenario 2, mouth conditions are like the present regime, while under Scenario 1, 3 and 4 the mouth of the estuary will be less open than under the current conditions. Scenario 4 shows a significant decline in open conditions from the present. Surprisingly, Scenario 1 and 2 showed the most shift in marine connectivity with peak connectivity shifting to October and August respectively.



	Natural	Present	Sc1: RCP 4.5 Mid	Sc 2: RCP 4.5 Far	Sc 3: RCP 8.5 Mid	Sc 4: RCP 8.5 Far
Closed	70.6	78.3	79.2	78.1	80.4	86.1
Open	29.4	21.7	20.8	21.9	19.6	13.9

Figure C.3: Klein: Overall occurrence of open mouth conditions (expressed as % open) under different scenarios

Table C.7: Klein: Estimated percentage time estuary is connected to the sea under different scenarios (darker colours indicate high connectivity and light colours low connectivity)

	KLEIN: PRESENT				KLEIN: SCENARIO 1				KLEIN: SCENARIO 2				KLEIN: SCENARIO 3				KLEIN: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (84 YEAR SIMULATION PERIOD)																				
January	7	7	7	7	13	13	13	13	18	18	18	18	12	12	12	12	4	4	4	4
February	5	5	5	5	4	4	4	4	4	4	4	4	2	2	2	2	1	1	1	1
March	5	5	5	5	6	6	6	6	4	4	4	4	5	5	5	5	2	2	2	2
April	6	6	6	6	4	4	4	4	6	6	6	6	8	8	8	8	6	6	6	6
May	12	12	12	12	12	12	12	12	11	11	11	11	8	8	8	8	8	8	8	8
June	23	23	23	23	15	15	15	15	27	27	27	27	17	17	17	17	15	15	15	15
July	30	30	30	30	24	24	24	24	33	33	33	33	24	24	24	24	20	20	20	20
August	46	46	46	46	36	36	36	36	43	43	43	43	38	38	38	38	31	31	31	31
September	46	46	46	46	38	38	38	38	36	36	36	36	38	38	38	38	30	30	30	30
October	40	40	40	40	44	44	44	44	36	36	36	36	38	38	38	38	27	27	27	27
November	29	29	29	29	35	35	35	35	29	29	29	29	30	30	30	30	14	14	14	14
December	12	12	12	12	20	20	20	20	18	18	18	18	15	15	15	15	7	7	7	7

Average water levels are relatively similar under Scenario 1 and increase slightly under Scenarios 2 to 4. However, it should be noted that this increase in average water levels is the result of an increase in the occurrence of the closed states, which off-set the loss of higher water levels under natural conditions. A broad summary is provided below in Table C.8.

Table C.8: Klein: Predicted water level (m) under Present State and Future Climate Change Scenarios

	KLEIN: PRESENT				KLEIN: SCENARIO 1				KLEIN: SCENARIO 2				KLEIN: SCENARIO 3				KLEIN: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (84 YEAR SIMULATION PERIOD)																				
January	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.5	1.5	1.5	1.5
February	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
March	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.5	1.5	1.5	1.5
April	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
May	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
June	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.2	1.2	1.2	1.2	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
July	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4
August	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3
September	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3
October	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3
November	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.4	1.4	1.4	1.4
December	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
PERCENTILE DISTRIBUTION (84 YEAR SIMULATION PERIOD)																				
99%ile	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
95%ile	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
90%ile	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
80%ile	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
70%ile	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
60%ile	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
50%ile (median)	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
40%ile	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
30%ile	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
20%ile	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
10%ile	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
1%ile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Salinity regimes under Scenario 1 to 4 are very similar to the present. There is a slight increase in salinity under scenarios 1 and 4. In most scenarios the decrease in State 1: Open Marine is offset by an increase in State 3: Closed Marine. A summary of the result is presented in Table C.9.

Table C.9: Klein: Predicted salinity under Present State and Future Climate Change Scenarios

	KLEIN: PRESENT				KLEIN: SCENARIO 1				KLEIN: SCENARIO 2				KLEIN: SCENARIO 3				KLEIN: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (84 YEAR SIMULATION PERIOD)																				
January	29	29	29	23	30	30	30	24	30	30	29	23	29	29	29	23	29	29	29	23
February	29	29	29	23	29	29	29	24	29	29	29	23	29	29	29	23	29	29	29	24
March	29	29	29	24	29	29	28	23	29	29	29	23	29	28	28	23	28	28	28	23
April	29	29	29	23	29	29	29	24	28	28	28	22	29	28	28	22	29	28	28	22
May	29	29	28	22	29	28	28	22	29	28	28	22	29	29	28	22	28	28	28	22
June	29	29	27	20	29	29	28	22	30	30	29	21	29	29	28	21	29	29	28	21
July	29	29	27	19	29	29	27	20	30	30	29	20	29	29	28	21	29	29	28	21
August	30	29	26	17	29	29	27	18	29	28	26	17	30	30	28	19	29	29	27	19
September	30	30	29	19	30	30	29	20	29	29	28	19	30	30	29	20	30	30	29	21
October	30	30	29	20	31	31	29	20	29	29	28	19	30	30	29	20	29	29	29	21
November	29	29	29	21	31	31	30	22	29	29	29	21	30	30	30	22	29	29	29	22
December	29	29	29	23	30	30	30	23	29	29	29	22	29	29	29	23	29	29	29	23
PERCENTILE DISTRIBUTION (84 YEAR SIMULATION PERIOD)																				
99%ile	35	35	35	25	35	35	35	25	35	35	35	25	35	35	35	25	35	35	35	25
95%ile	35	35	35	25	35	35	35	25	35	35	35	25	35	35	35	25	35	35	35	25
90%ile	35	35	35	25	35	35	35	25	35	35	35	25	35	35	35	25	35	35	30	25
80%ile	35	35	30	25	30	30	30	25	35	35	30	25	30	30	30	25	30	30	30	25
70%ile	30	30	30	25	30	30	30	25	30	30	30	25	30	30	30	25	30	30	30	25
60%ile	30	30	30	25	30	30	30	25	30	30	30	25	30	30	30	25	30	30	30	25
50%ile (median)	30	30	30	25	30	30	30	25	30	30	30	25	30	30	30	25	30	30	30	25
40%ile	30	30	30	25	30	30	30	25	30	30	30	24	30	30	30	25	30	30	30	25
30%ile	30	30	30	20	30	30	30	20	30	30	30	20	30	30	30	20	30	30	30	20
20%ile	30	30	25	15	30	30	25	15	30	30	25	15	30	30	25	15	30	30	25	15
10%ile	20	20	20	15	20	20	20	15	20	20	20	15	20	20	20	15	20	20	20	15
1%ile	20	15	10	0	20	15	10	0	20	15	10	0	20	20	20	10	20	20	20	10

Predicted changes in seasonal and percentile distribution of water quality under present and future Climate Change scenarios are provided in Table C.10. Present water quality in the Klein has been significantly modified by anthropogenic pollution inputs, in this case mostly wastewater and agricultural return flow. Except for Scenario 4, it is unlikely that the predicted shifts in rainfall and temperature, associated with the Future Climate Change Scenarios, will cause measurable shifts from the Present State. Scenario 4 predicted the highest decrease in State 4 (Open, marine) which suggest a slight deterioration of water quality from the Present, due to a decrease in marine flushing.

Table C.10: Klein: Predicted water quality under Present State and Future Climate Change Scenarios

	KLEIN: PRESENT				KLEIN: SCENARIO 1				KLEIN: SCENARIO 2				KLEIN: SCENARIO 3				KLEIN: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																				
January	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5
February	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5
March	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5
April	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5
May	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5
June	4	4	5	5	4	5	5	5	3	4	5	5	4	4	5	5	4	5	5	5
July	3	4	4	5	4	4	4	5	3	4	4	5	4	4	4	5	4	4	4	5
August	3	4	4	5	3	4	4	5	3	4	4	5	3	4	4	5	3	4	4	5
September	3	4	4	5	3	4	4	5	3	4	4	5	3	4	4	5	3	4	4	5
October	3	4	4	5	3	4	4	5	3	4	4	5	3	4	4	5	3	4	4	5
November	3	4	4	5	3	4	4	5	3	4	4	5	3	4	4	5	4	5	5	5
December	4	5	5	5	4	5	5	5	4	4	5	5	4	5	5	5	4	5	5	5
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																				
95%ile	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5
90%ile	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5
80%ile	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5
70%ile	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5
60%ile	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5
50%ile (median)	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5
40%ile	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5	4	5	5	5
30%ile	4	4	4	5	4	4	4	5	4	4	4	5	4	4	4	5	4	4	4	5
20%ile	2	3	4	5	3	4	4	5	2	3	4	5	4	4	4	5	4	4	4	5
10%ile	2	3	3	4	2	3	3	4	2	3	3	4	2	3	3	4	2	3	4	5

C.3 Biotic Responses

C.3.1 Microalgae

The conceptual model for microalgal characteristics under different abiotic scenarios is illustrated in Figure C.4, while the microalgal characteristics associated with different zone are summarised in Table C.11.

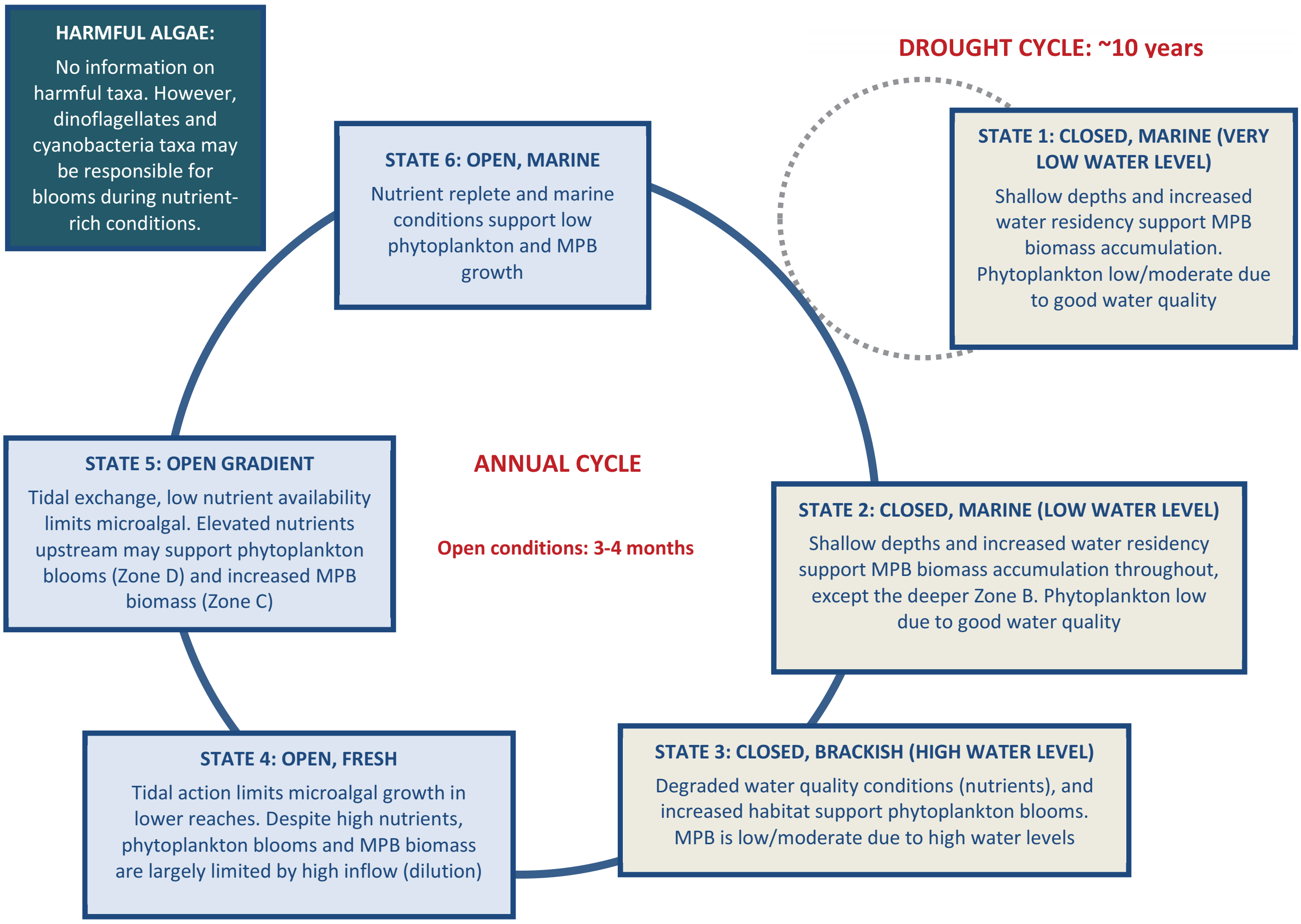


Figure C.4 Klein: Microalgae Conceptual model

Phytoplankton blooms (≥ 20 µg Chl-a µg/ℓ) have been recorded in the estuary (Anchor, 2015). Such events are typical of the shallow upper reaches (Zone C) and constrained river portion (Zone D). A key driver of bloom conditions is nutrient availability, and therefore such instances can be expected during closed, brackish conditions (State 3) that are characterised by high water levels (~increased habitat availability) and degraded water quality (~WWTW inputs). Despite a lack of available data, benthic microalgal biomass is expected to peak during shallow conditions (excluding Zone B) with increased water residency. There is a lack of information regarding the presence of harmful algal species in the system, however, harmful taxa belonging to Dinophyceae (dinoflagellates), Cyanophyceae (cyanobacteria), Cryptophyceae and Euglenophyceae (euglenoids) could be expected during nutrient-rich periods. *Microcystis* sp. has been recorded to form blooms in the estuary during periods of mouth closure and low water levels. Due to the large size of Zone B, wind-driven circulation is expected to largely hinder phytoplankton productivity.

Table C.11: Klein: Key microalgal characteristics associated with various states

STATE	PARAMETER	ZONE A	ZONE B	ZONE C	ZONE D
State 1: Closed, marine (very low water level)	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				
State 2: Closed, marine (low water level)	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				
State 3: Closed, brackish (high water level)	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				
State 4: Open, fresh	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				
State 5: Open, gradient	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				
State 6: Open, marine	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				

Confidence levels: Phytoplankton – Medium; Benthic microalgae – Low; Harmful algae – Low

A summary of the key responses in microalgae under the Present State and Future Climate Change scenarios are summarized in Table C.12. Predicted changes in seasonal and percentile distribution of microalgae under present and future Climate Change scenarios are provided in Tables C.13 to C.15.

Table C.12: Klein: Summary of Microalgae responses under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Microalgal growth has increased compared to reference conditions due to the increased availability of nutrients, reduced freshwater inflow, and more prolonged periods of mouth closure. This is particularly the case for phytoplankton in Zone C and D during low inflow periods characterised by longer water residence times. Wind-mixing typically hinders microalgal growth in the large main basin (Zone B).
1-3	The predicted marginal reductions in freshwater inflow and open mouth conditions for these scenarios are not expected to result in any marked increases in microalgal growth.
4	Significant reductions in flow (10% < than present) and open mouth states, together with a 4°C increase in temperature and more pronounced effect of WWTW inputs, are expected to increase the occurrence of phytoplankton blooms and harmful algae (e.g. dinoflagellates and cyanobacteria).

Table C.13: Predicted Phytoplankton under Present State and Future Climate Change Scenarios

	KLEIN: PRESENT				KLEIN: SCENARIO 1				KLEIN: SCENARIO 2				KLEIN: SCENARIO 3				KLEIN: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																				
January	3	3	4	4	3	3	4	4	3	3	3	4	3	3	4	4	3	4	4	5
February	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	4	4	5
March	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	4	4	5
April	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	4	4	5
May	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	4	4	5
June	3	3	3	4	3	3	4	4	2	2	3	4	3	3	3	4	3	3	4	5
July	2	2	3	4	3	3	3	4	2	2	3	4	3	3	3	4	3	3	4	4
August	2	2	3	4	2	2	3	4	2	2	3	4	2	2	3	4	2	3	4	4
September	2	2	3	4	2	2	3	4	2	2	3	4	2	2	3	4	2	3	3	4
October	2	2	3	4	2	2	3	4	2	2	3	4	2	2	3	4	2	3	4	4
November	2	2	3	4	2	2	3	4	2	2	3	4	2	2	3	4	3	3	4	5
December	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	3	4	4	5
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																				
95%ile	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	4	4	5
90%ile	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	4	4	5
80%ile	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	4	4	5
70%ile	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	4	4	5
60%ile	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	4	4	5
50%ile (median)	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	4	4	5
40%ile	3	3	4	4	3	3	4	4	3	3	4	4	3	3	4	4	3	4	4	5
30%ile	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	4	4
20%ile	1	1	2	4	2	3	3	4	1	1	2	4	3	3	3	4	3	3	4	4
10%ile	1	1	1	3	1	1	1	3	1	1	1	3	1	1	1	3	1	2	3	4

Table C.14: Klein: Predicted Benthic microalgae under Present State and Future Climate Change Scenarios

	KLEIN: PRESENT				KLEIN: SCENARIO 1				KLEIN: SCENARIO 2				KLEIN: SCENARIO 3				KLEIN: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																				
January	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
February	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
March	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
April	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
May	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
June	3	2	3	3	3	2	3	3	2	2	3	3	3	2	3	3	3	2	3	3
July	2	2	3	3	3	2	3	3	2	2	3	3	3	2	3	3	3	2	3	3
August	2	2	3	3	2	2	3	3	2	2	3	2	2	2	3	3	2	2	3	3
September	2	2	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2	3	3
October	2	2	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2	3	3
November	2	2	2	3	2	2	2	3	2	2	3	3	2	2	2	3	3	2	3	3
December	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																				
95%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
90%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
80%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
70%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
60%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
50%ile (median)	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
40%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
30%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
20%ile	1	1	3	2	1	1	3	2	1	1	3	2	3	2	3	2	3	2	3	3
10%ile	1	1	1	2	1	1	1	2	1	1	1	2	1	1	1	2	1	1	3	3

Table C.15: Klein: Predicted Harmful algae under Present State and Future Climate Change Scenarios

	KLEIN: PRESENT				KLEIN: SCENARIO 1				KLEIN: SCENARIO 2				KLEIN: SCENARIO 3				KLEIN: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																				
January	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
February	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
March	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
April	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
May	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
June	3	2	3	3	3	2	3	3	2	2	3	3	3	2	3	3	3	2	3	3
July	2	2	3	3	3	2	3	3	2	2	3	3	3	2	3	3	3	2	3	3
August	2	2	3	3	2	2	3	3	2	2	3	2	2	2	3	3	2	2	3	3
September	2	2	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2	3	3
October	2	2	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2	3	3
November	2	2	2	3	2	2	2	3	2	2	3	3	2	2	2	3	3	2	3	3
December	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																				
95%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
90%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
80%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
70%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
60%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
50%ile (median)	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
40%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
30%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3
20%ile	1	1	3	2	1	1	3	2	1	1	3	2	3	2	3	2	3	2	3	3
10%ile	1	1	1	2	1	1	1	2	1	1	1	2	1	1	1	2	1	1	3	3

C.3.2 Macrophytes

Salt marsh and salt pans occur in the lower estuarine section around the mouth and in the low-lying regions, the southern banks, middle reaches and less so in the northern banks where it is steeper. Two species (*Cotula filifolia* and *Limonium scabrum*) are endemic to South Africa and *Cotula myriophylloides* is classified as Critically Endangered on the IUCN red list. Reeds and sedges (mainly *Phragmites australis*) fringe the middle and upper reaches of the estuary where salinity is suitable for their establishment. Reeds and sedges are common in the upper riverine section. They are restricted to 1.5 m depth (Figure C.5).

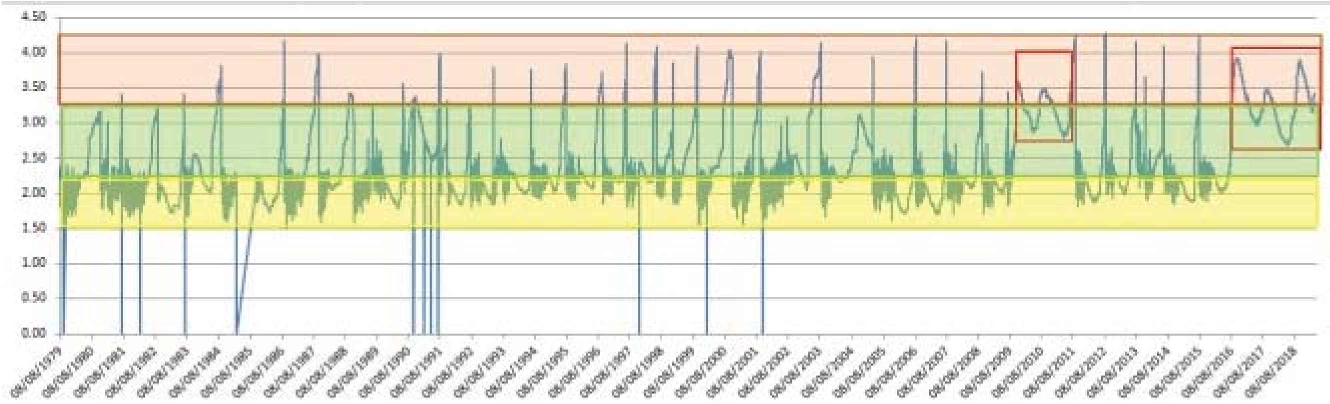


Figure C.5: Klein: Historical water level readings for the Klein Estuary. Yellow = water level at which salt marsh mainly occurs, (< 2.2 MSL). Green box = predominantly submerged macrophytes, with salt marsh and reeds to a lesser extent (2.2 to 3.2 MSL). Pink box = submerged macrophytes and reeds dominant (> 3.2 MSL). Red boxes = periods of longer mouth closure due to drought

The macrophyte conceptual model for Klein is presented in Figure C.6.

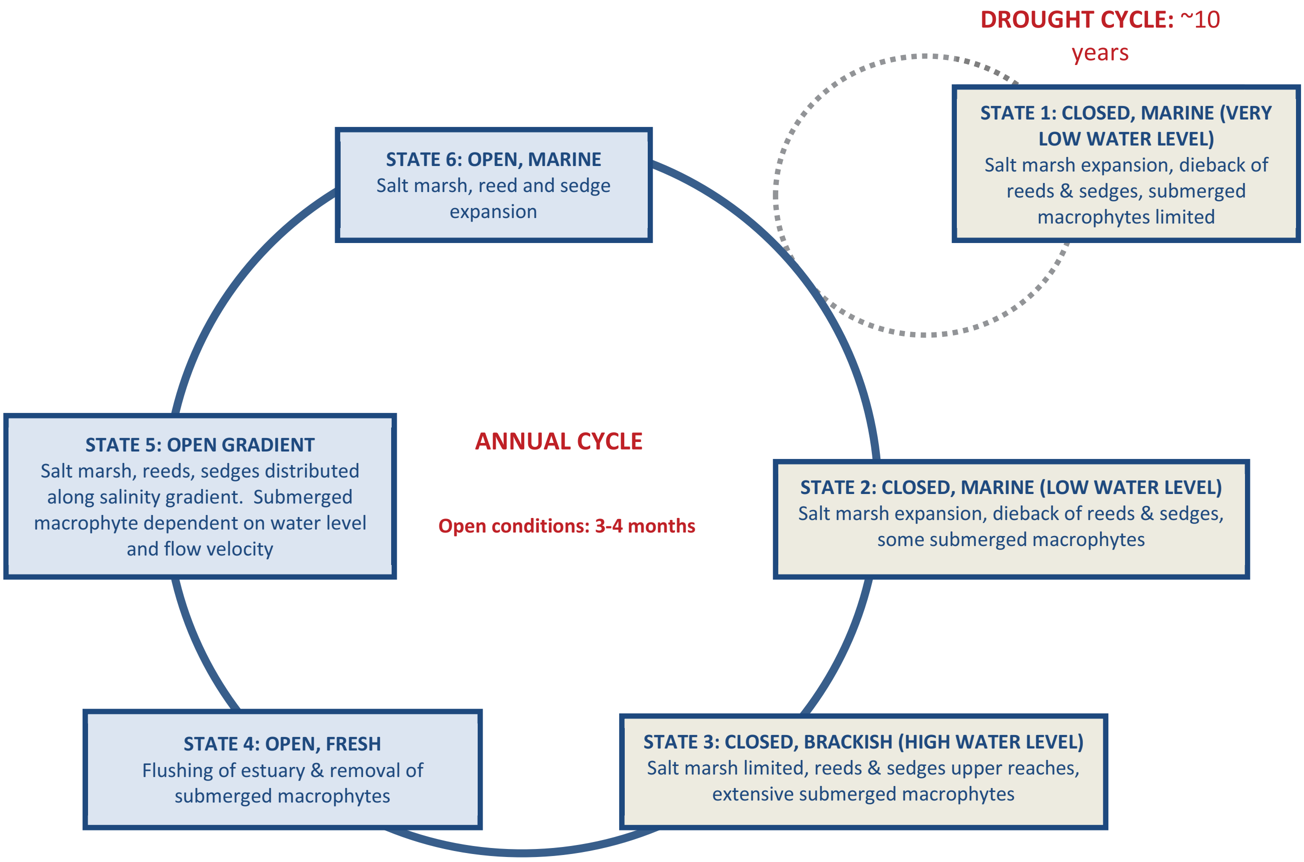


Figure C.6 Klein: Macrophyte Conceptual model

Water level, salinity and to a lesser extent nutrient concentration determine macrophyte habitat area and species composition (Figure C.7). Analysis of historical water level taken from the water level gauge G4T004 for the period 1979 to 2019 showed that maximum water level occurs approximately once a year (Figure C.8). By comparing dates of Google Earth images and available habitat with the water level at the time of the image taken, it appears that a water level of 3.2 MSL is a threshold for macrophyte habitat distribution. Above 3.2 m MSL salt marsh areas become flooded and replaced by submerged macrophytes, along with an expansion of reeds. At levels below 2.5 MSL salt marsh and reeds flourish. Submerged macrophyte will also be present but limited due to the shallow water. Open conditions and high-water velocity will also restrict their growth. As salt marsh floods with the increasing water level, the habitat dies back and macroalgae often develop in response to the nutrient input because of the decomposition. Reed growth is seasonal but can also respond to sediment input with an increase in shallower areas (Figure 11.7). The estuary shows signs of eutrophication with large filamentous green macroalgal blooms occurring throughout the estuary particularly during the closed mouth state. For future climate change scenarios (e.g. Scenario 4) an increase in temperature will also favour growth of macroalgae.

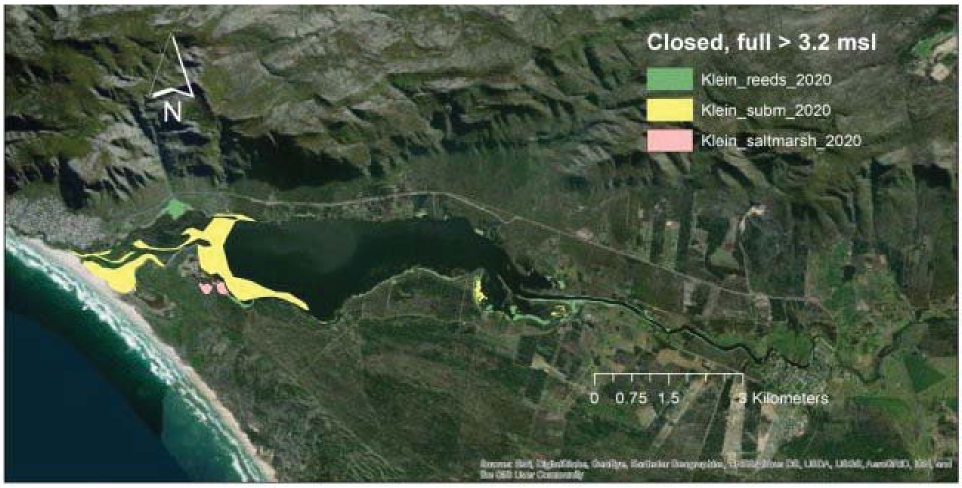
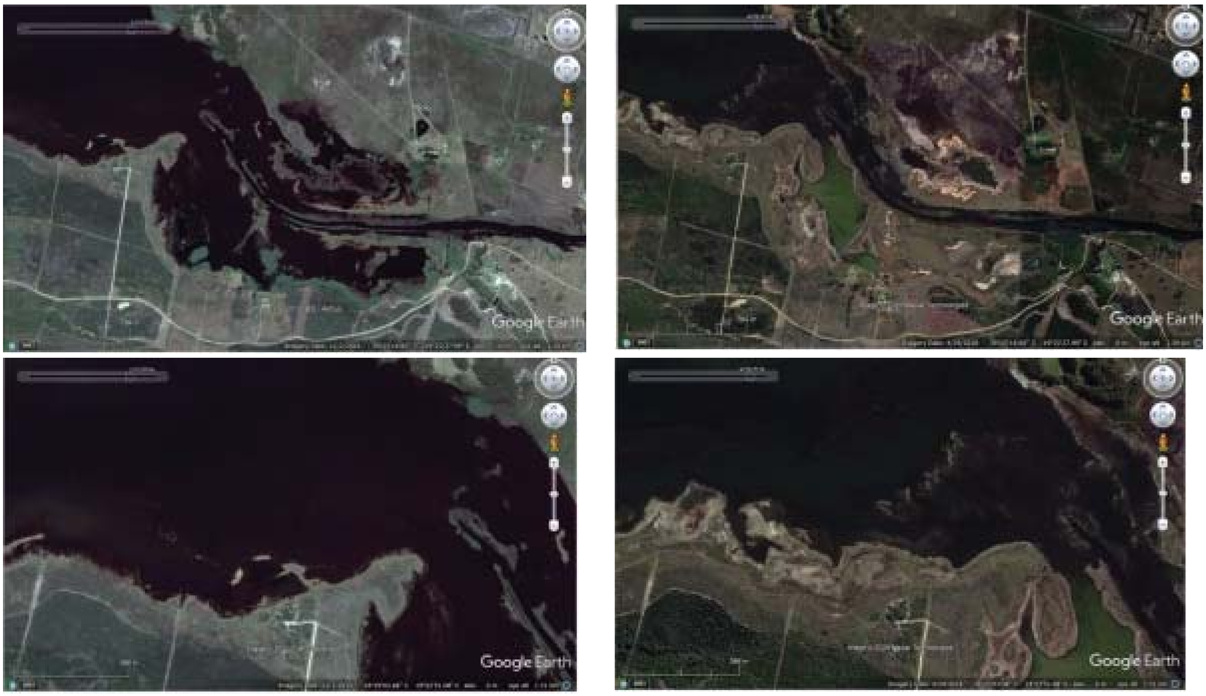


Figure C.7 Klein: Macrophyte distribution

Different submerged macrophytes occur in the estuary in response to salinity changes, e.g. *Stuckenia pectinata* (< 15), *Ruppia cirrhosa* (brackish conditions but can occur in salinity up to 75) and *Zostera capensis* (prefers marine conditions). The latter species is more prevalent in the Klein Estuary compared with the Bot possibly due to higher salinity and longer periods when the mouth is open. Also, *Zostera* can occur in intertidal conditions whereas *Stuckenia* and *Ruppia* are intolerant of desiccation and will die when exposed.



Low water level (2018 right) and salt marsh growth near the riverine section after high water level in 2016 (left).

Figure C.8: Klein: Macrophyte images indicating macrophyte responses at a range of water levels

Responses of Macrophytes to different scenarios are illustrated in Tables C.16 to C.18.

Table C.16: Klein: Response of macrophytes to water level changes (Green = salt marsh and increasing red = submerged macrophytes. Rules < 1.3 m salt marsh and > 1.5 m submerged macrophytes. Salinity all within *Potamogeton* and not *Ruppia* tolerance range therefore not shown)

	PRESENT				SCENARIO 1				SCENARIO 2				SCENARIO 3				SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (84 YEAR SIMULATION PERIOD)																				
Jan	1.44	1.44	1.44	1.44	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.38	1.38	1.38	1.38	1.48	1.48	1.48	1.48
Feb	1.45	1.45	1.45	1.45	1.41	1.41	1.41	1.41	1.47	1.47	1.47	1.47	1.48	1.48	1.48	1.48	1.47	1.47	1.47	1.47
Mar	1.42	1.42	1.42	1.42	1.38	1.38	1.38	1.38	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.47	1.47	1.47	1.47
Apr	1.41	1.41	1.41	1.41	1.42	1.42	1.42	1.42	1.43	1.43	1.43	1.43	1.38	1.38	1.38	1.38	1.43	1.43	1.43	1.43
May	1.37	1.37	1.37	1.37	1.36	1.36	1.36	1.36	1.43	1.43	1.43	1.43	1.44	1.44	1.44	1.44	1.45	1.45	1.45	1.45
Jun	1.32	1.32	1.32	1.32	1.36	1.36	1.36	1.36	1.22	1.22	1.22	1.22	1.38	1.38	1.38	1.38	1.39	1.39	1.39	1.39
Jul	1.28	1.28	1.28	1.28	1.33	1.33	1.33	1.33	1.21	1.21	1.21	1.21	1.31	1.31	1.31	1.31	1.36	1.36	1.36	1.36
Aug	1.07	1.07	1.07	1.07	1.20	1.20	1.20	1.20	1.13	1.13	1.13	1.13	1.18	1.18	1.18	1.18	1.27	1.27	1.27	1.27
Sep	1.13	1.13	1.13	1.13	1.19	1.19	1.19	1.19	1.30	1.30	1.30	1.30	1.22	1.22	1.22	1.22	1.27	1.27	1.27	1.27
Oct	1.20	1.20	1.20	1.20	1.10	1.10	1.10	1.10	1.28	1.28	1.28	1.28	1.19	1.19	1.19	1.19	1.28	1.28	1.28	1.28
Nov	1.29	1.29	1.29	1.29	1.17	1.17	1.17	1.17	1.29	1.29	1.29	1.29	1.24	1.24	1.24	1.24	1.40	1.40	1.40	1.40
Dec	1.42	1.42	1.42	1.42	1.29	1.29	1.29	1.29	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.43	1.43	1.43	1.43

Connectivity and water level are the two main drivers of habitat change and are therefore shown monthly below. Salinity will determine species response.

Table C.17: Klein: Predicted change in macrophyte AREA (increase=↑ or decrease=↓) from the present

PRESENT	J	F	M	A	M	J	J	A	S	O	N	D
Submerged	↑	↑	↑	↑	↑	↓	↓	↓	↓	↑	↑	↑
Salt marsh	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Reeds & sedges	↑	↑	↑	↓	↓	↓	↓	↓	↑	↑	↑	↑
Macroalgae	↑	↑	↑	↓	↓	↓	↓	↓	↓	↓	↑	↑
SCENARIO 1	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Submerged	↑	↑	↑	↑	↑	↓	↓	↓	↓	↓	↑	↑
Salt marsh	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Reeds & sedges	↑	↑	↑	↓	↓	↓	↓	↓	↑	↑	↑	↑
Macroalgae	↑	↑	↑	↓	↓	↓	↓	↓	↓	↑	↑	↑
SCENARIO 2	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Submerged	↑	↑	↑	↑	↑	↓	↓	↓	↓	↑	↑	↑
Salt marsh	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Reeds & sedges	↑	↑	↑	↓	↓	↓	↓	↓	↑	↑	↑	↑
Macroalgae	↑	↑	↑	↓	↓	↓	↓	↓	↓	↓	↑	↑
SCENARIO 3	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Submerged	↑	↑	↑	↑	↑	↑	↑	↓	↓	↑	↑	↑
Salt marsh	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Reeds & sedges	↑	↑	↑	↑	↑	↑	↑	↓	↓	↑	↑	↑
Macroalgae	↑	↑	↑	↓	↓	↓	↓	↓	↓	↑	↑	↑
SCENARIO 4	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Submerged	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Salt marsh	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Reeds & sedges	↑	↑	↑	↓	↓	↓	↓	↓	↑	↑	↑	↑
Macroalgae	↑	↑	↑	↓	↓	↓	↓	↓	↓	↓	↑	↑

Table C.18: Klein: Summary of Macrophytes responses under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Salt marsh and submerged macrophyte are present in Zones A, B and C, depending on water level. Salinity will determine which submerged macrophyte species are present. Reeds and sedges occur in the upper reaches of the shallow Zone C and in the riverine section, Zone D. (Salt marsh = 205.72 ha, Reeds and sedges = 91.72 ha, Submerged macrophytes = 76.9 ha, Open water = 1084.98 ha) From reference to present there has been a decline in macrophyte species richness due to a reduction in baseflow and increase in salinity. Some macrophyte habitat (35 ha) has clearly been lost due to development, agriculture, and invasive species. Large areas of the floodplain (110 ha) have been disturbed by human activity. Nutrient enrichment has encouraged growth of macroalgae which in turn has resulted in a loss in the area covered by submerged macrophytes due to shading. Increases in salinity and the development of saltpans have also caused a reduction in the density and cover of salt marsh plants.
1	Flow, water level, salinity similar to the present, macrophytes similar to the present.
2	A slight decrease in flow, macrophytes similar to the present. However, the increase in water level due to mouth closure in September and October will influence seed germination and decrease salt marsh cover.
3	A decrease in flow by 5%, increase in closed mouth state. Reeds and sedges ↓ Salt marsh ↓ Submerged macrophytes ↑ macroalgae ↑
4	Flow decreases by ~10% compared to present, increase in the closed marine state. Reeds and sedges ↓ Salt marsh ↓ Submerged macrophytes ↑ macroalgae ↑ Because of the higher salinity, submerged macrophytes will be the more salt-tolerant (*Ruppia cirrhosa*) that will replace the less salt-tolerant species (*Stuckenia pectinata*). Mouth closure and increase in nutrients will promote macroalgal growth as well as a 3 to 4°C increase in temperature.

C.3.3 Fish

A total of 51 fish species from 27 families have been recorded from the Klein Estuary (Anchor 2015). Including all Category Ia, Ib, IIa & V species, 23 (45%) of these are entirely dependent on estuaries to complete their lifecycle. Ten of these breed in estuaries and include the estuarine round-herring *Gilchristella aestuaria*, Bot River klipvis *Clinus spatulatus*, Cape halfbeak *Hyporhamphus capensis*, Cape silverside *Atherina breviceps*, Knysna sand-goby *Psammogobius knysnaensis*, four *Caffrogobius* species, Cape halfbeak *Hyporhamphus capensis* and pipefish *Syngnathus temminckii*. Nine, including dusky kob *Argyrosomus japonicus*, white steenbras *Lithognathus lithognathus*, leervis *Lichia amia*, Cape moony *Monodactylus falciformis*, flathead mullet *Mugil cephalus*, freshwater mullet *Myxus capensis* and Cape stumpnose *Rhabdosargus holubi*, are dependent on estuaries as nursery areas for at least their first year of life. A further three, namely the catadromous African mottled eel *Anguilla bengalensis*, Madagascan mottled eel *A. marmorata* and longfin eel *A. mossambica* require estuaries as transit routes between the marine and freshwater environment. In addition, *Mugil cephalus* and *Myxus capensis* may be regarded as facultative catadromous species (Whitfield 1994). Another 10 (20%) species, e.g. harder *Liza richardsonii*, groovy mullet *Liza dumerilii*, elf *Pomatomus saltatrix* and white stumpnose *Rhabdosargus globiceps* are at least partially dependent on estuaries. In all, 65% of can be regarded as either partially or completely dependent on estuaries for their survival. Eleven of the remaining species are marine species, e.g. piggy *Pomadasys olivaceum* and wildeperd *Diplodus hottentotus*, which occur in, but are not dependent on estuaries; while seven, the indigenous Cape galaxias *zebratus* and Cape kurper *Sandelia capensis* and introduced carp *Cyprinus carpio*, largemouth *M. salmoides*, smallmouth *M. dolomieu* and spotted bass *M. punctatus*, Mozambique tilapia *Oreochromis mossambicus* and banded tilapia *T. sparrmanii* are alien euryhaline freshwater species whose penetration into estuaries is determined by salinity tolerance.

In many respects, the composition of the Klein Estuary fish assemblage is identical to that of the Bot/Kleinmond Estuary. Species that breed in estuaries and/or estuarine residents make up 20% of the Klein and Bot. Species that are entirely dependent on estuaries comprise 45% of the Klein Estuary fish fauna versus 46% for the Bot. Partially estuarine dependent species comprise 20% of the Klein and Bot fish fauna (Bennett 1994, Lamberth et al. 2008). Non estuary-dependent marine species comprise a relatively low proportion (20%) of the fish species recorded in the Klein, and most, e.g. gurnard *Chelidonichthys capensis* and smooth houndshark *Mustelus mustelus,* can be construed as rare vagrants which seldom enter estuaries. Their occurrence in the temporarily open/closed Klein is largely a function of their chance proximity to the mouth when it was open. Based on their distributional ranges given by Smith and Heemstra (1986), 26 (51%) of the fish recorded in the Klein Estuary are southern African endemics including the Botriver klipvis *Clinus spatulatus* which has an extremely limited range being confined to the Klein and Bot/Kleinmond systems. The fish conceptual model for Klein is presented in Figure C.9

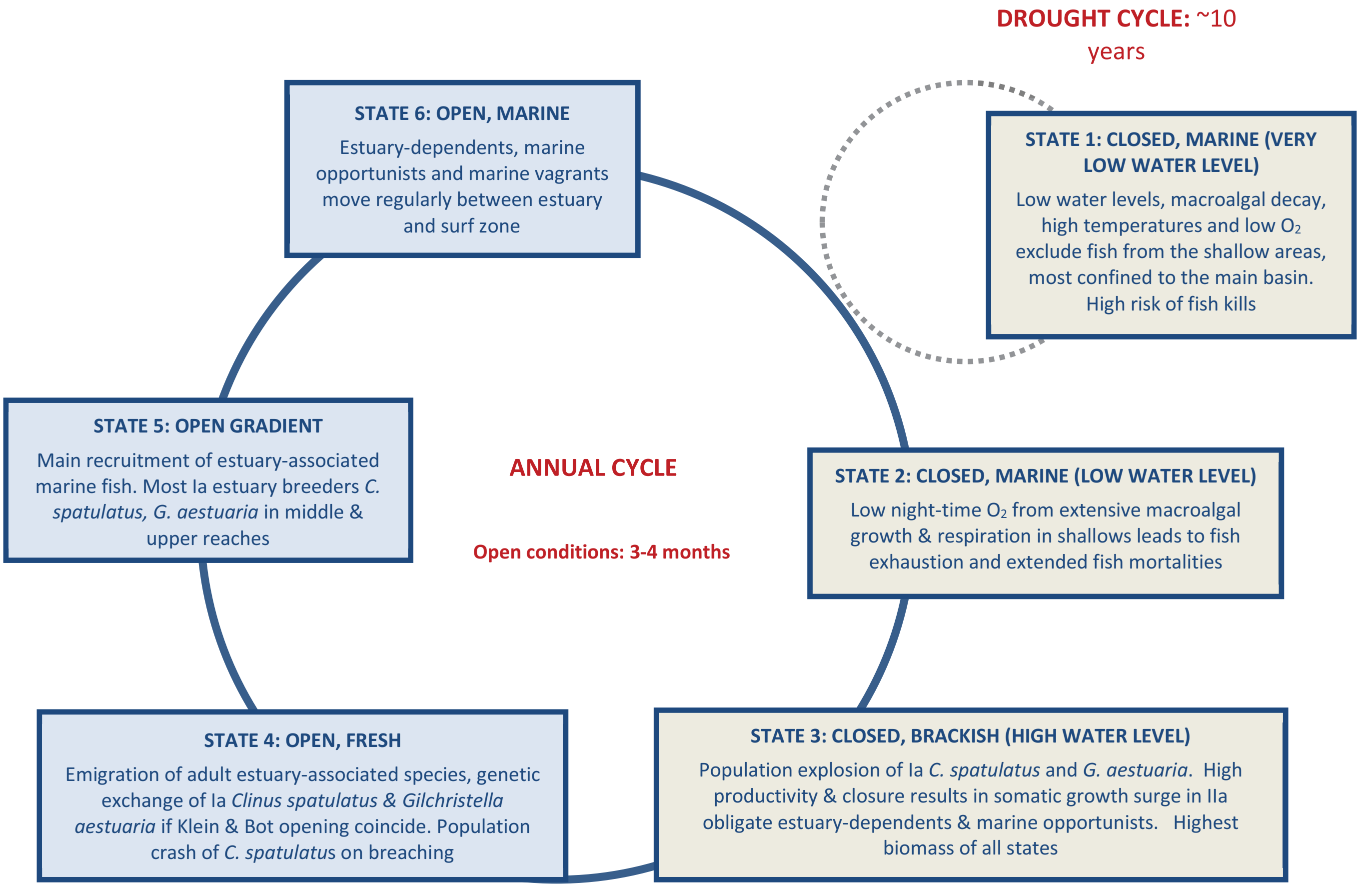


Figure C.9: Klein: Fish Conceptual Model

Predicted changes in response to different scenarios are summarised in Table C.19.

Table C.19: Klein: Predicted change in fish under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Species Richness: Overall, 51 species were recorded in the estuary. Similar to reference and *Clinus spatulatus* has persisted in the system and has been subject to fewer population fluctuations than the Bot over the past 15 years. However, some estuarine-dependent species of very low numbers and functionally absent from the estuary whereas 6 alien species now in the upper reaches (Zone D). Marine species absent from the estuary. Abundance: Numerically dominant *A. breviceps* and *G.aestuaria* have not changed much since reference but there has been a severe drop in recruitment and survival of estuarine-dependent marine species in the system more specifically those exploited. Further, in more than 250 seine hauls over 15 years, only 4 individual category III marine vagrants were caught. Freshwater invasives have established and increased in abundance in the upper reaches. Community composition: Piscivorous fish specifically in much lower numbers, e.g. L. amia or absent, e.g. *A. japonicus* from the estuary. Small estuary-resident fodder fish are probably unchanged, but gillnet poaching has reduced numbers of marine opportunistic Mugillidae and therefore detritivores in the estuary. Introduced *Oreochromis mossambicus* herbivorous but also a fierce nest defender and being much larger usurps indigenous *Sandelia capensis* from the upper reaches.
1	Flow, water level, salinity similar to the present. A slight increase in closed conditions. Fish similar to the present.
2	A slight decrease in flow, fish similar to the present.
3	Decrease in flow by 5%, increase in closed mouth state. A decrease in fish abundance, loss of marine species.
4	Flow decreases by ~10% compared to present, increase in the closed marine state. Increase in Harmful algae. Potential increase in low oxygen events. Reeds and sedges ↓ **Salt** marsh ↓ Submerged macrophytes ↑ macroalgae ↑. A decline in fish abundance and species richness Fish buffered against increase temperature as the deeper areas in the Klein will provide refuge against temperatures exceeding 40° C

D. HEUNINGNES

D.1 Predicted Climate Change Scenarios

Predicted climate change scenarios for RCP 4.5 and 8.5 under mid and far future scenarios relevant to the Klein, are presented in Tables D.1 to D.3 for precipitation in the catchment, precipitation in EFZ and ambient atmospheric temperature, respectively. A summary of broad measures of hydrological changes, as reported by Cullis et al. (2015), is provided in Table D.4.

Table D.1: Heuningnes: Predicted change in precipitation in catchment for RCP 4.5 and 8.5 under mid- and far-future scenarios

CATCHMENT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	14	-11	-23	-31	-15	-14	-17	9	-4	55	-21	0
RCP 4.5 Far	40	4	-16	-14	-4	-16	-16	21	-16	23	-17	13
RCP 8.5 Mid	21	1	-12	-6	-6	-18	-12	-7	0	7	7	12
RCP 8.5 Far	31	-5	-1	-14	-10	-13	-33	-3	-15	-4	-20	19

Table D.2: Heuningnes: Predicted change in precipitation in EFZ for RCP 4.5 and 8.5 under mid- and far-future scenarios

ESTUARY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	2	-23	-26	-35	-12	-6	-9	14	-1	69	-26	-13
RCP 4.5 Far	19	2	-13	-20	6	-6	-13	15	-13	31	-19	7
RCP 8.5 Mid	5	-6	-15	0	-8	-16	-6	-9	1	11	1	19
RCP 8.5 Far	20	-6	-3	-12	-9	-8	-26	0	-19	-4	-30	8

Table D.3: Heuningnes: Predicted increase in ambient atmospheric temperature (°C) for RCP 4.5 and 8.5 under mid- and far-future scenarios

TAve	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	1.4	1.4	1.3	1.6	1.5	1.7	1.6	1.4	1.4	1.4	1.1	1.6
RCP 4.5 Far	1.7	1.7	1.6	2.0	1.4	1.8	2.2	2.5	2.2	1.9	1.4	2.1
RCP 8.5 Mid	1.5	1.3	1.3	1.9	1.7	2.3	2.1	2.0	2.1	2.0	1.7	1.8
RCP 8.5 Far	3.2	3.1	3.2	3.5	4.2	3.9	3.8	3.6	3.7	3.6	3.5	3.2
Tmax	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	1.0	1.1	1.2	1.7	1.2	1.8	1.4	1.0	1.2	1.2	0.9	1.5
RCP 4.5 Far	1.2	1.4	1.6	2.2	1.3	1.8	2.3	2.3	2.2	1.6	1.2	1.9
RCP 8.5 Mid	1.1	1.1	1.0	1.8	1.4	2.3	2.0	1.8	2.0	1.7	1.5	1.5
RCP 8.5 Far	2.6	2.7	2.6	3.1	3.5	3.4	3.7	3.1	3.3	3.3	3.2	2.7
Tmin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	1.8	1.6	1.5	1.5	1.8	1.6	1.8	1.7	1.7	1.5	1.4	1.6
RCP 4.5 Far	2.1	1.9	1.7	1.9	1.5	1.8	2.2	2.7	2.2	2.2	1.7	2.3
RCP 8.5 Mid	2.0	1.6	1.6	1.9	2.1	2.3	2.2	2.2	2.2	2.3	2.0	2.2
RCP 8.5 Far	3.8	3.6	3.7	3.9	5.0	4.4	4.0	4.0	4.1	4.0	3.8	3.8

Table D.4: Heuningnes: Summary of broad measures of hydrological change (as reported by Cullis et al. 2015)

PARAMETER	PERCENTAGE CHANGE
Median Flows	-20%
Q 1 (Low flows)	-20%
Q 3 (Floods)	-20%
Min	-30%
Max	-5%

Table D.5 provide a summary of potential change in runoff under RCP 4.5 and 8.5 scenarios for mid and far future conditions.

Table D.5: Heuningnes: Summary of potential change in the runoff under RCP 4.5 and 8.5 scenarios for mid and far future conditions

SCENARIO NAME	DESCRIPTION	MAR (x 10^6 m^3)	PERCENTAGE REMAINING
Natural	Reference condition	32.39	
Present	Present	27.35	84.4
Scenario 1	RCP 4.5 Mid	27.37	84.5
Scenario 2	RCP 4.5 Far	27.43	84.7
Scenario 3	RCP 8.5 Mid	28.68	88.5
Scenario 4	RCP 8.5 Far	24.03	74.2

While most of these scenarios represent a relatively small change in overall MAR, it should be noted that most of this flow has been removed from the low flow periods, with little, to no baseflow, being the norm for 4 to 7 months of the year. Scenario 4 represents a 10% decline in flow to the system.

D.2 Abiotic Responses

D.2.1 Abiotic states and key characteristics

The characteristic abiotic states (and associated distinctive temporal patterns) for the Heuningnes, are illustrated conceptually in Figure D.1.

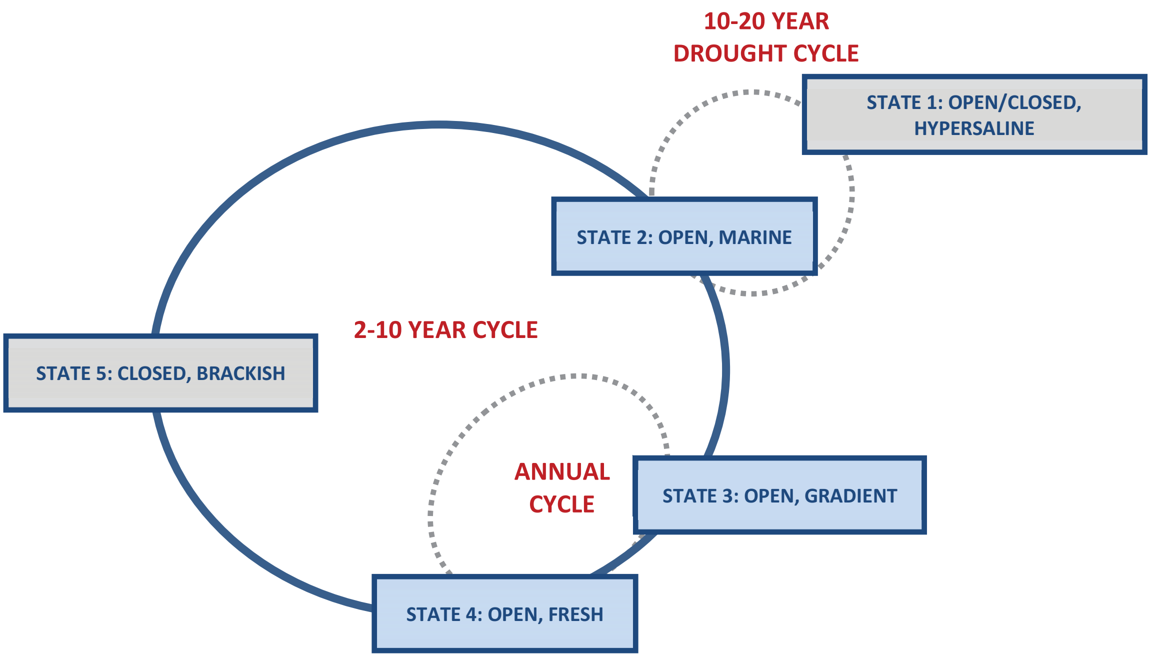


Figure D.1: Heiningnes: Distinctive temporal patterns in the distribution of abiotic states (present)

While little information is available on historical mouth dynamics of the Heuningnes under natural conditions; the volume of river inflow and the estuary geomorphology (volume of the estuary) alludes to intermitted closures occurring decades apart. However, because of the flat topography of the area, inundation would have resulted in a very large open water area that would have taken anything from 2 to 10 years to fill up, given variable inflow, seepage and evaporative losses (Anchor 2018).

This large body of water would have resulted in extremely high outflow velocities, which in turn would have resulted in a deep basin in the lower reaches and enhanced tidal flows that would have assisted in keeping the mouth open for decades after a breaching. In addition, the mouth position would have shifted depending on the lowest-lying point in the frontal dune system, adding additional variability to this complex interaction between river flow, tidal exchange, and sediment processes.

At present, the mouth of the Heuningnes Estuary has been artificially manipulated since the early 1940s to prevent backflooding of riparian properties (Anchor 2018). The concern was that flooding would result in damage to structures and loss of land under crops due to a combination of prolonged inundation and elevated salinity levels that would accumulate in the soils. The practice of actively stabilizing dunes on either side of the mouth and erecting barriers to trap longshore wind-blown sand was stopped in 2012 pending further studies.

The mouth has remained largely open since then without manipulation, although sediment build-up in the lower reaches is extensive and closure during low flow periods an imminent prospect. The mouth has closed on only a few occasions since the 1940s. For example, it was closed for three years between 1973 and 1976 but was eventually manually breached when the system started to fill after good rains. The mouth also closed in August 2007, but it was again manually breached on 24 September 2007 after rains threatened to flood the riparian areas.

During extended drought conditions large parts of the lower estuary can become hypersaline and the littoral zone and the shallow parts Soetendalsvlei exposed (e.g. 2019/2020 unpublished data). Under natural conditions, this was most likely associated with closed mouth conditions, but can also occur under artificial induced open mouth conditions.

Five abiotic states have been identified in the Heuningnes Estuary (Table D.6), with *State 1: Open/closed hypersaline* associated with drought conditions at decadal scales as reflected in the extremely low water levels (0-0.5 m) in Soetendalsvlei (Zone D) and the formation of hypersalinity (40-45) in the middle and upper reaches (Zone B and C) of the tidal part of the system. Soetendalsvlei's salinity is expected to range from 5 to 10.

Table D.6: Heuningnes: Key abiotic characteristics associated with various states

STATE	PARAMETER	ZONE A	ZONE B	ZONE C	ZONE D
State 1: Open/closed hypersaline	WL:	0.5-1 m (tide 30 cm)/ 0.5-1.0 m (closed)			0-0.5 m
	Salinity:	**35-40**	**40**	**45**	**5-10**
	Temp:	Summer: 18-26°C; Winter 12-15°C			
	WQ:	**NN(2)**	**HM**	**HM**	**MM**
State 2: Open, marine	WL:	0.5-1.3 m			1.0-1.5
	Salinity:	35	30	20	0
	Temp:	Summer: 18-26°C; Winter 12-15°C			
	WQ:	**NN(1)**	**NN(2)**	**MM**	**MM**
State 3: Open, gradient	WL:	0.5-1.3 m			1.5-2.0
	Salinity:	**35**	**15**	**0**	**0**
	Temp:	Summer: 18-26°C; Winter 12-15°C			
	WQ:	**NN(2)**	**NN(2)**	**MM**	**MM**
State 4: Open, fresh	WL:	0-1.3 m			2.0-3.0
	Salinity:	**10**	**1**	**0**	**0**
	Temp:	Summer: 18-26°C; Winter 12-15°C			
	WQ:	**MM**	**MM**	**MM**	**MM**
State 5: Closed, brackish	WL:	1.8-3.0 m			
	Salinity:	**15**	**10**	**10**	**1**
	Temp:	Summer: 18-26°C; Winter 12-15°C			
	WQ:	**MM**	**HM**	**HM**	MM

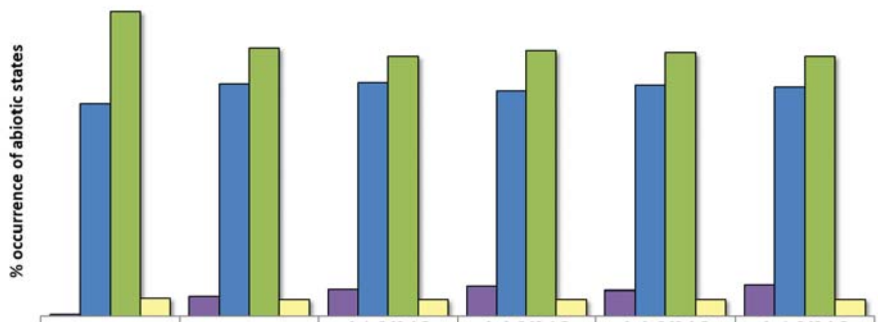
During *State 2: Open, marine* the mouth of the estuary is open to the sea, with water levels in Soetendalsvlei between 1.0 to 1.5 m MSL. Salinity in the tidal part of the system (Zone A to C) will be largely marine and vary between 20 and 35, while Soetendalsvlei (Zone D) is expected to be fresh. This state is largely associated with the summer low flow season. In *State 3: Open, gradient* the salinity in the lower reaches of the tidal part of the system range from 35 near the mouth (Zone A) to brackish (Zone B) to fresh (Zone C). Soetendalsvlei will be fresh with water levels between 1.5 to 2.0 m. While under *State 4: Open, fresh* the salinity in the tidal part of the system ranges from 0 to 10 near the mouth (Zone A). Soetendalsvlei will be fresh with water levels between 2.0 to 3.0 m. *State 5: Closed, brackish* represents a closed mouth state with salinity in the lower part of the system ranging from 10 to 15 (Zone A to C) and Soetendalsvlei (Zone D) about 1. Water levels will vary between 1.8 to 3.0 m.

It is expected that agricultural activities in the catchment have resulted in some nutrient enrichment, affecting overall water quality, but not to such an extent of resulting in excessive eutrophication in the water column. Dense reed beds around Soetendalsvlei (Zone D) may have been fuelled by agricultural runoff into the Nuwejaars River, but the reeds are acting as a 'nutrient filter' for the open water body of the vlei only resulting in slightly higher nutrient levels. This 'nutrient filter' may not be as efficient for runoff entering the lower estuary from the Kars River. As a result, higher nutrient levels are being introduced into the lower estuary (Zones B and C), more so during higher river flow (i.d. lower salinity) (Anchor 2018).

D.2.2 Responses to climate change scenarios

The Heuninges responds to river flow in all its variability during its open state. However, once closed breaching is largely dependent on higher flows and flood events to reach breaching levels. Predicted changes in hydrodynamic functioning, average water level, salinity and marine connectivity are captured in the overall occurrence of different abiotic states in the Heuningnes estuary are summarised in Figure D.2.

The largest shift has been from natural to present with a significant decrease in State 3: Open Gradient conditions. This trend is also observed under Scenarios 1 to 4. Scenario 4 represents the most change towards a more saline system. Notable is the increase in State 1: Open/Close hypersaline conditions under Scenario 4.



	Natural	Present	Sc1: RCP 4.5 Mid	Sc 2: RCP 4.5 Far	Sc 3: RCP 8.5 Mid	Sc 4: RCP 8.5 Far
State 1: Open/Closed hypersaline	0.4	3.8	5.0	5.6	4.9	5.8
State 2: Open Marine	39.5	43.2	43.4	41.9	42.9	42.6
State 3: Open Gradient	56.7	49.8	48.4	49.4	49.0	48.4
State 4: Open Fresh	3.4	3.1	3.1	3.1	3.1	3.1

Figure D.2 Heuningnes: Occurrence of abiotic states under different scenarios

No data was readily available to correlate river inflow with the limited mouth closure records available. Mouth closure could thus not be systematically determined. However simulated river inflow data, the estuary bathymetry and present mouth behaviour, all paint a picture of intermitted closures occurring decades apart. However, because of the flat topography of the area, inundation would have resulted in a very large open water area that would have taken anything from 2 to 10 years to fill up, given variable inflow, seepage and evaporative losses. When full, this significant body of water would have resulted in extremely high outflow velocities, which in turn would have resulted in a deep basin in the lower reaches and enhanced tidal flows that would have assisted in keeping the mouth open for decades after a breaching. In addition, the mouth position would have shifted depending on the lowest-lying point in the frontal dune system, adding additional variability to this complex interaction between river flow, tidal exchange, and sediment processes (Table D.7).

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

Table D.7: Heuningnes: Summary of potential change in mouth state under RCP 4.5 and 8.5 scenarios for mid and far future conditions

SCENARIO NAME	DESCRIPTION	MOUTH CLOSURE
Natural	Reference condition	1-5% risk of closure & remain close for 2-10 years
Present	Present	~ 10% risk of closure & remain close 1-3 years (assume artificial breaching at > 2 m MSL).
Scenario 1	RCP 4.5 Mid	~12% risk of closure & remain close for 1-4 years (assume artificial breaching at > 2 m MSL)
Scenario 2	RCP 4.5 Far	
Scenario 3	RCP 8.5 Mid	
Scenario 4	RCP 8.5 Far	>15% risk of closure & remain close for 1-5 years (assume artificial breaching at > 2 m MSL)

There is little change in the water level between the scenarios considering State 1 to 4 (Table D.8). The lake level tends to be higher than the tidal section of the system, with the highest water levels achieved towards the end of winter. However, prolonged closure (not factored in below) under Scenario 4 could lead significantly to disrupt this cycle and lead to 1 to 3 years of very low to low water levels followed by a year or two of elevated water levels.

Table D.8: Heuningnes: Predicted water level (m) under Present and Future Climate change Scenarios

HEUNINGNES: PRESENT					SCENARIO 1				SCENARIO 2				SCENARIO 3				SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (85 YEAR SIMULATION PERIOD)																				
January	0.6	0.6	0.6	1.3	0.6	0.6	0.6	1.3	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.3	0.6	0.6	0.6	1.3
February	0.6	0.6	0.6	1.3	0.6	0.6	0.6	1.3	0.6	0.6	0.6	1.3	0.6	0.6	0.6	1.3	0.6	0.6	0.6	1.3
March	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.3	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.4
April	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.3	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.4
May	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.3	0.6	0.6	0.6	1.3	0.6	0.6	0.6	1.3	0.6	0.6	0.6	1.3
June	0.6	0.6	0.6	1.6	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.4
July	0.5	0.5	0.5	1.7	0.5	0.5	0.5	1.7	0.5	0.5	0.5	1.7	0.5	0.5	0.5	1.6	0.5	0.5	0.5	1.6
August	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.7
September	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8
October	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8
November	0.5	0.5	0.5	1.6	0.5	0.5	0.5	1.6	0.5	0.5	0.5	1.6	0.5	0.5	0.5	1.6	0.5	0.5	0.5	1.6
December	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.4	0.6	0.6	0.6	1.4
PERCENTILE DISTRIBUTION (85 YEAR SIMULATION PERIOD)																				
99%ile	1.0	1.0	1.0	2.5	1.0	1.0	1.0	2.5	1.0	1.0	1.0	2.5	1.0	1.0	1.0	2.5	1.0	1.0	1.0	2.5
95%ile	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	1.0	1.0	1.0	1.8	0.6	0.6	0.6	1.8	1.0	1.0	1.0	1.8
90%ile	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8
80%ile	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8
70%ile	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8
60%ile	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8
50%ile (median)	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8	0.5	0.5	0.5	1.8
40%ile	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3
30%ile	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3
20%ile	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3
10%ile	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3	0.5	0.5	0.5	1.3
1%ile	0.3	0.3	0.3	0.5	0.3	0.3	0.3	0.5	0.3	0.3	0.3	0.5	0.3	0.3	0.3	0.5	0.3	0.3	0.3	0.5

A comparison of salinity regimes under the future climate conditions shows that Scenarios 1 to 4 all present slight increases to the present, mostly around late summer to early autumn. Scenario 4 also indicates an increase in State 1: Open/Close hypersaline – representative of drought conditions. A summary of the result is presented in Table D.9.

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Table D.9: Heuningnes: Predicted salinity under Present State and Future Climate Change Scenarios

	HEUNINGNES: PRESENT				SCENARIO 1				SCENARIO 2				SCENARIO 3				SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (85 YEAR SIMULATION PERIOD)																				
January	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
February	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
March	35	27	17	0	35	28	18	0	35	28	18	0	35	27	17	0	35	27	17	0
April	34	25	15	0	35	26	17	1	35	26	17	1	35	26	16	1	35	26	16	1
May	34	25	15	1	34	26	17	1	34	26	18	1	34	26	17	1	34	26	17	1
June	34	21	10	1	34	23	14	1	34	24	16	1	34	23	14	1	34	24	16	1
July	34	17	4	0	35	16	2	0	35	15	1	0	35	18	5	0	35	18	4	0
August	33	15	1	0	33	15	1	0	33	15	1	0	33	15	1	0	33	16	3	0
September	33	14	0	0	33	14	0	0	33	14	0	0	33	14	0	0	33	14	0	0
October	34	16	2	0	33	15	2	0	33	15	2	0	33	15	1	0	33	15	2	0
November	35	20	7	0	35	20	7	0	35	20	7	0	35	20	7	0	35	19	6	0
December	35	27	16	0	35	27	16	0	35	26	14	0	35	26	15	0	35	26	15	0
PERCENTILE DISTRIBUTION (85 YEAR SIMULATION PERIOD)																				
99%ile	35	40	45	5	35	40	45	5	35	40	45	5	35	40	45	5	35	40	45	5
95%ile	35	30	20	0	35	30	21	0	35	40	45	5	35	30	20	0	35	40	45	5
90%ile	35	30	20	0	35	30	20	0	35	30	20	0	35	30	20	0	35	30	20	0
80%ile	35	30	20	0	35	30	20	0	35	30	20	0	35	30	20	0	35	30	20	0
70%ile	35	30	20	0	35	30	20	0	35	30	20	0	35	30	20	0	35	30	20	0
60%ile	35	30	20	0	35	30	20	0	35	30	20	0	35	30	20	0	35	30	20	0
50%ile (median)	35	15	0	0	35	15	0	0	35	15	0	0	35	15	0	0	35	15	0	0
40%ile	35	15	0	0	35	15	0	0	35	15	0	0	35	15	0	0	35	15	0	0
30%ile	35	15	0	0	35	15	0	0	35	15	0	0	35	15	0	0	35	15	0	0
20%ile	35	15	0	0	35	15	0	0	35	15	0	0	35	15	0	0	35	15	0	0
10%ile	35	15	0	0	35	15	0	0	35	15	0	0	35	15	0	0	35	15	0	0
1%ile	10	1	0	0	10	1	0	0	10	1	0	0	10	1	0	0	10	1	0	0

Predicted changes in seasonal and percentile distribution of water quality under Present and Future Climate Change Scenarios are provided in Table D.10. Present water quality in the lower estuary of the Heuningnes is still in a near-natural state, while the middle and upper reaches has been moderately modified. While results suggest slight changes in percentile distribution under some of the Climate Change Scenarios (e.g. Scenarios 2 and 3), these are not expected to result in a measurable change in the water quality of this system compared with the Present.

Table D.10: Predicted water quality for the Heuningnes Estuary under Present State and Future Climate change Scenarios

	HEUNINGNES: PRESENT				HEUNINGNES: SCENARIO 1				HEUNINGNES: SCENARIO 2				HEUNINGNES: SCENARIO 3				HEUNINGNES: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																				
January	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3
February	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3
March	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3
April	1	3	3	3	1	3	3	3	1	3	3	3	1	3	3	3	1	3	3	3
May	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
June	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
July	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
August	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
September	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
October	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
November	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
December	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																				
95%ile	2	3	3	3	2	3	3	3	2	4	4	3	2	3	3	3	2	4	4	3
90%ile	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
80%ile	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
70%ile	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
60%ile	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
50%ile (median)	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
40%ile	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3
30%ile	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3
20%ile	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3
10%ile	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3	1	2	3	3

D.3 Biotic Responses

D.3.1 Microalgae

The conceptual model for microalgae characteristics under different abiotic scenarios is illustrated in Figure D.3, while the microalgal characteristics associated with different zone are summarised in Table D.11.

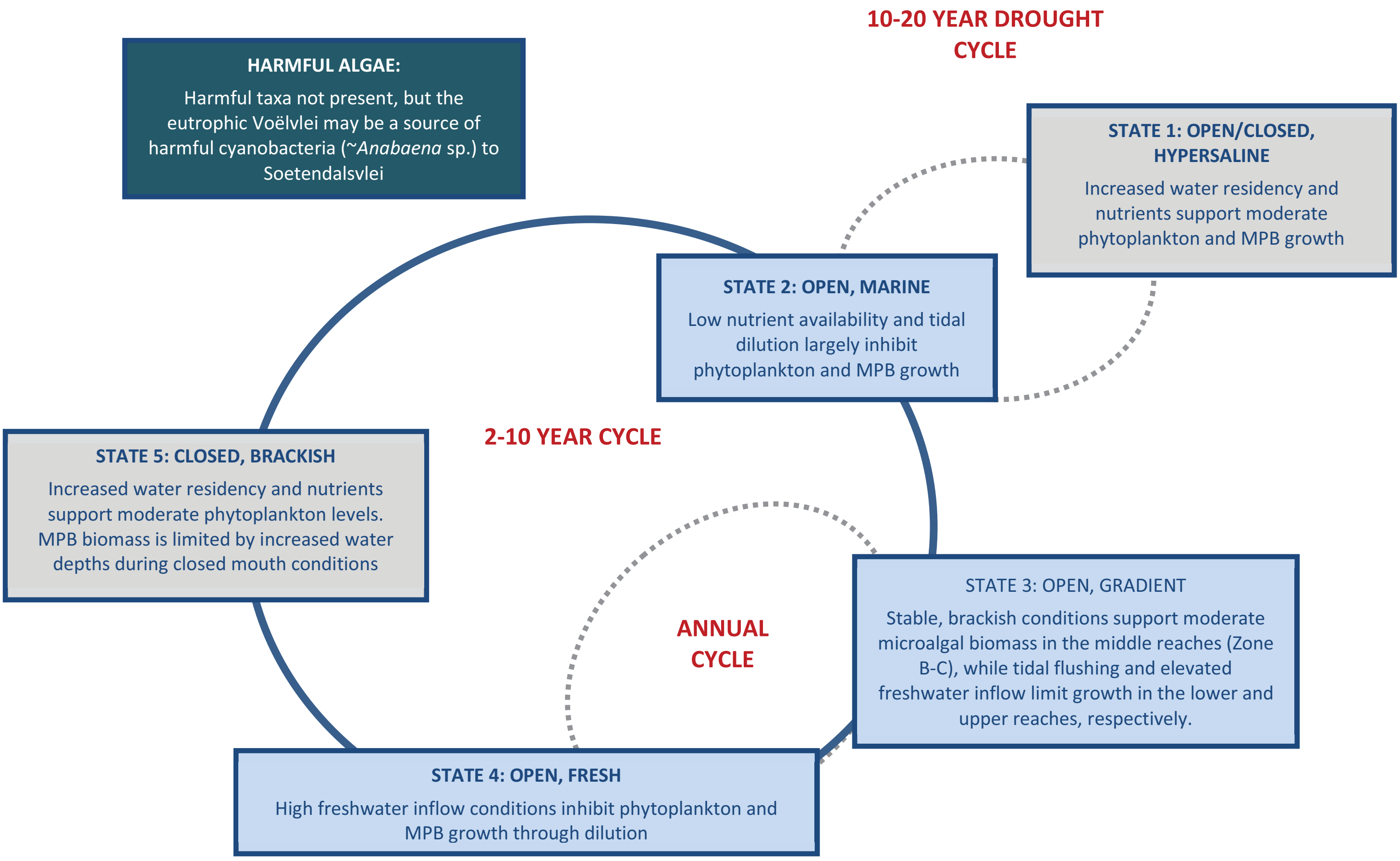


Figure D.3: Heuningnes: Microalgae Conceptual model

Phytoplankton biomass levels in the Heuningnes Estuarine Lake system are typically low (~Good: < 5 µg/ℓ) (Gordon et al., 2011; Gordon, 2012). However, increased water residency periods and nutrient availability (~State 1 and 5), together with brackish, stratified conditions (State 3), are likely to support elevated phytoplankton biomass (~Fair: ≥ 5 but < 20 µg/ℓ). Bacillariophyceae (diatoms), Dinophyceae (dinoflagellates) and other motile phytoplankton classes (e.g. Euglenophyceae and Chlorodendrophyceae) are dominant during marine and brackish conditions (Zone A-C). Oligohaline conditions, characteristic of Soetendalsvlei (Zone D) and high inflow periods (State 3 and 4), are accompanied by increased abundance of Chlorophyceae (greens), Cyanophyceae (cyanobacteria) and freshwater diatoms. Despite the paucity of available data, benthic microalgal biomass is expected to be predominantly low (~Good: < 50 mg/m^2) due to elevated water levels and tidal dilution (State 2-4), with slight increases (~Fair: ≥ 50 but < 100 mg/m^2) probable during low water levels, elevated nutrient availability and increased water residency (~State 1 and 5) (Table D.11). The presence of harmful algal species is unlikely given the largely oligotrophic state of the system; however, blooms of cyanobacterial species (e.g. *Anabaena* sp.) in the eutrophic Voëlvlei wetland, suggest a possible source of harmful taxa to the downstream Soetendalsvlei (Zone D).

Table D.11: Heuningnes: Key microalgal characteristics associated with various states

STATE	PARAMETER	ZONE A	ZONE B	ZONE C	ZONE D
State 1: Open/closed hypersaline	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				
State 2: Open, marine	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				
State 3: Open, gradient	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				
State 4: Open, fresh	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				
State 5: State 5: Closed, brackish	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				

Confidence levels: Phytoplankton – Medium; Benthic microalgae – Low; Harmful algae – Low

A summary of the key responses in microalgae under the Present State and Future Climate Change scenarios are summarized in Table D.12. Predicted changes in seasonal and percentile distribution of microalgae under present and future Climate Change scenarios are provided in Tables D.13 to D.15.

Table D.12: Heuningnes: Predicted change in Microalgae under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Phytoplankton growth and the presence of HAB species is low due to low in-situ nutrient availability and tidal exchange during open mouth states. However, benthic microalgal growth has increased from natural due to reduced freshwater inflow and water levels.
1-3	With little change predicted for the abiotic environment (e.g. hydrology and nutrients), microalgal communities are expected to be similar to present.
4	Significant reductions in flow (10% < than present) and open mouth states (i.e. prolonged hypersaline/drought periods), as well as a 4°C increase in temperature, are expected to increase the microalgal biomass throughout the system, with the occurrence of HAB species becoming more likely (e.g. cyanobacteria).

Table D.13: Heuningnes: Predicted Phytoplankton under Present State and Future Climate Change Scenarios

	HEUNINGNES: PRESENT				HEUNINGNES: SCENARIO 1				HEUNINGNES: SCENARIO 2				HEUNINGNES: SCENARIO 3				HEUNINGNES: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																				
January	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
February	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
March	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
April	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	2	2	2	2
May	1	2	3	2	1	2	3	2	1	2	3	2	1	2	3	2	2	2	3	3
June	1	2	3	2	1	2	3	2	1	2	3	2	1	2	3	2	2	2	3	3
July	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	2	2	3	3	3
August	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	2	2	3	3	3
September	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	2	2	3	3	3
October	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	2	2	3	3	3
November	1	2	3	2	1	2	3	2	1	2	3	2	1	2	3	2	2	2	3	3
December	1	1	2	2	1	1	2	2	1	2	2	2	1	1	2	2	1	2	2	2
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																				
95%ile	1	3	3	2	1	3	3	2	2	3	3	3	1	3	3	2	3	3	3	3
90%ile	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	2	2	3	3	3
80%ile	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	2	2	3	3	3
70%ile	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	2	2	3	3	3
60%ile	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	2	2	3	3	3
50%ile (median)	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	2	2	3	3	3
40%ile	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
30%ile	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
20%ile	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
10%ile	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2

Table D.14: Heuningnes: Predicted Benthic microalgae under Present State and Future Climate Change Scenarios

	HEUNINGNES: PRESENT				HEUNINGNES: SCENARIO 1				HEUNINGNES: SCENARIO 2				HEUNINGNES: SCENARIO 3				HEUNINGNES: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																				
January	1	3	3	3	1	3	3	3	1	3	3	3	1	3	3	3	2	3	3	3
February	1	3	3	3	1	3	3	3	1	3	3	3	1	3	3	3	2	3	3	3
March	1	3	3	3	1	3	3	3	1	3	3	3	1	3	3	3	2	3	3	3
April	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
May	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
June	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	3
July	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2
August	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2
September	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2
October	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2
November	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2
December	1	3	3	3	1	3	3	3	1	3	3	3	1	3	3	3	2	3	3	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																				
95%ile	2	3	3	3	2	3	3	3	3	4	4	3	2	3	3	3	4	4	4	4
90%ile	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
80%ile	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
70%ile	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
60%ile	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
50%ile (median)	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2
40%ile	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	2	2	3	3	2
30%ile	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	2	2	3	3	2
20%ile	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	2	2	3	3	2
10%ile	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	2	2	3	3	2

Table D.15: Heuningnes: Predicted Harmful algae under Present State and Future Climate Change Scenarios

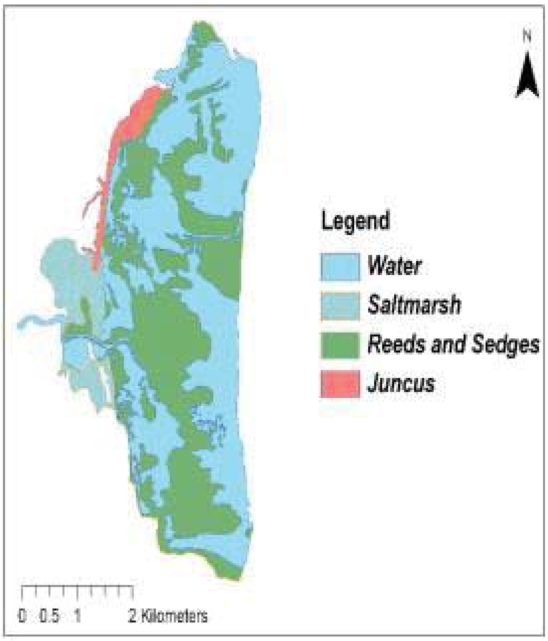
	HEUNINGNES: PRESENT				HEUNINGNES: SCENARIO 1				HEUNINGNES: SCENARIO 2				HEUNINGNES: SCENARIO 3				HEUNINGNES: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																				
January	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
February	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
March	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
April	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	2
May	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2	2	2	2
June	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2	2	2	2
July	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2	2	2	2
August	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2	2	2	2
September	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2	2	2	2
October	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2	2	2	2
November	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2	2	2	2
December	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																				
95%ile	1	2	2	1	1	2	2	1	1	3	3	3	1	2	2	1	2	3	3	3
90%ile	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2	2	2	2
80%ile	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2	2	2	2
70%ile	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2	2	2	2
60%ile	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2	2	2	2
50%ile (median)	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2	2	2	2
40%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
30%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

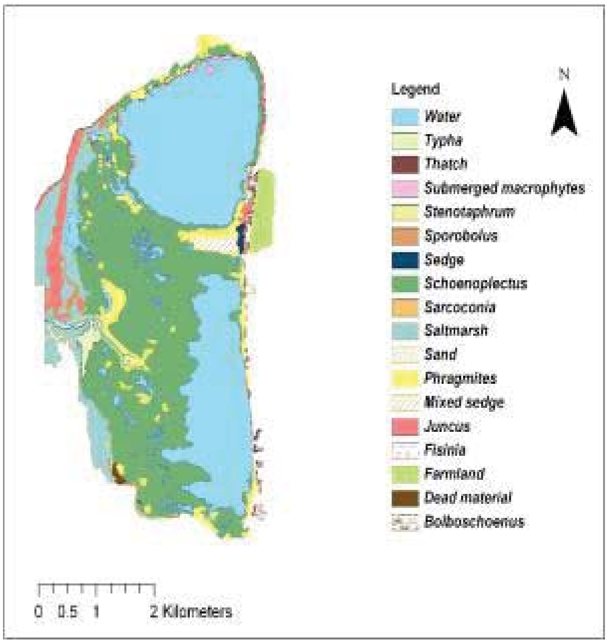
D.3.2 Macrophytes

The dominant macrophyte habitats in the Heuningnes Estuary are seagrass and salt marsh. Large areas of salt marsh (*Limonium*, *Salicornia* and *Sarcocornia* spp.) occur in the lower and middle reaches, while stands of reeds and sedges (*Phragmites australis* and *Schoenoplectus scirpoides)* line the water channel in the upper reaches. Supratidal salt marsh consists of *Sarcocornia pillansii* and *Bassia diffusia* surrounds the wetland and is inundated under high rainfall events.

Historically Heuningnes River and estuary were connected to Soetendalsvlei. The latter now consists of large reed beds mainly *Phragmites australis* and *Schoenoplectus scirpoides* separating the vlei into a northern and southern section. Reed growth is restricted to the western shore due to high winds that blow throughout the year in the region (Gordon 2012). Shallowing of Soetendalsvlei through sediment input has resulted in the spread of reeds (Kotsedi 2007) (Figure D.3). Nutrient input from agricultural activities in the catchment can also increase reed growth. The submerged macrophyte *Stuckenia pectinata* (pondweed) was present in 2007.

Future climate change scenarios show small changes. There is an increase in State 1 for future scenarios particularly Scenario 4. This state represents hypersaline conditions associated with drought conditions at decadal scales. This also results in low water levels (0-0.5 m) in Soetendalsvlei (Zone D) and the formation of hypersalinity (40-45) in the middle and upper reaches (Zone B and C) of the tidal part of the system. Soetendalsvlei's salinity is expected to range between 5 and 10. The higher salinity will decrease the growth of reeds and sedges. Macroalgae will increase during the summer months in response to nutrient input and higher temperature. The macrophyte conceptual model for Heuningnes Estuary is presented in Figure D.5.





Low water and reed growth will expand in Soetendalsvlei as not limited by depth (28 April 2019)

Estuary mouth remains open – salt marsh visible (29 Nov 2019)

Figure D.4: Vegetation distribution in Soetendalsvlei in 1938 (left) and 2007 (right, Kotsedi 2007)

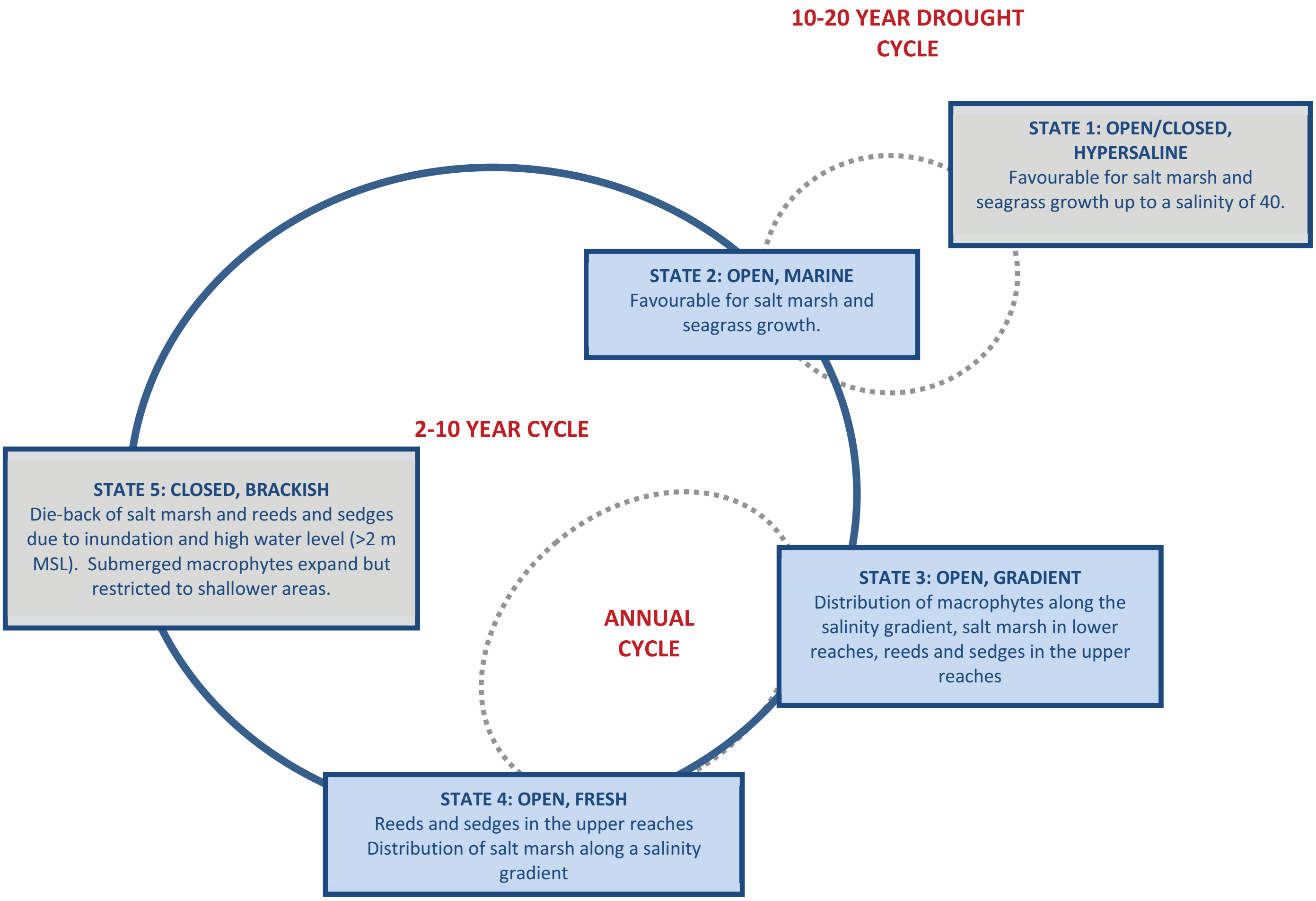


Figure D.5: Heuningnes: Macrophyte Conceptual model

Responses of Macrophytes to different scenarios are illustrated in Tables D.16 and D.17.

Table D.16: Heuningnes: Predicted macrophytes responses under future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present (60)	Intertidal salt marsh = 16.2 ha, Supratidal salt marsh = 660.4, Reeds and sedges = 1154.98 ha, Submerged macrophytes = 10.17 ha. There has been a significant transformation in the supratidal and floodplain habitat because of agricultural development, drainage canals, causeways/weirs and road crossings. Approximately 80% of the total vegetated area in the EFZ consists of agriculture and disturbed floodplain (3214.32 ha of 3999.48 ha).
1-3 (58)	There is an increase in State 1, closed hypersaline conditions. This occurs at decadal scales as reflected in the extremely low water levels (0-0.5 m) in Soetendalsvlei (Zone D) and the formation of hypersalinity (40-45) in the middle and upper reaches (Zone B and C) of the tidal part of the system. The higher salinity will decrease the growth of reeds and sedges in Zones B and C. Macroalgae will increase during the summer months in response to nutrient input and higher temperatures in all zones.
4 (56)	There is an increase in State 1, closed hypersaline conditions. Together with an increase in temperature and evaporation further changes in the macrophytes can be expected. The higher salinity will decrease the growth of reeds and sedges. Macroalgae will increase during the summer months in response to nutrient input and higher temperatures in all zones.

Table D.17: Heuningnes: Predicted change in macrophytes AREA from Present under Future Climate Change Scenarios

Present	J	F	M	A	M	J	J	A	S	O	N	D
Salt marsh	↑	↑	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Submerged	↓	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Reeds & sedges	↓	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑	↓
Macroalgae	↑	↑	↓	↓	↓	↓	↓	↓	↓	↓	↓	↑
Scenario 1, 2 & 3	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Salt marsh	↑	↑	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Submerged	↓	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Reeds & sedges	↓	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑	↓
Macroalgae	↑	↑	↓	↓	↓	↓	↓	↓	↓	↓	↓	↑
Scenario 4	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Salt marsh	↑	↑	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Submerged	↓	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Reeds & sedges	↓	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑	↓
Macroalgae	↑	↑	↓	↓	↓	↓	↓	↓	↓	↓	↓	↑

D.3.3 Fish

In total, 72 species of fish from 34 families have been recorded from the lake system (Anchor 2017). Resident fish that breed only in estuaries (Category Ia) comprise four species – estuarine round herring *Gilchristella aestuaria*, Cape halfbeak *Hyporamphus capensis*, kappie blenny *Omobranchus woodii* and the yet to be confirmed but unlikely Knysna seahorse *Hippocampus capensis*. Fish that breed in the marine and estuarine environments (Category Ib), e.g. estuarine pipefish *Syngnathus temminckii* and prison goby *Caffrogobius gilchristi*, were represented by seven species. Obligate estuary-dependent fish that have to spend at least the first year of life in estuaries (IIa), e.g. dusky kob *Argyrosomus japonicus* and white steenbras *Lithognathus lithognathus*, contributed 10 species whereas partially estuary-dependent (IIb), e.g. blackhand sole *Solea turbynei* and marine opportunists that use the best of both worlds (IIc), e.g. harder *Liza richardsonii* provided six and seven species, respectively.

Marine vagrants (III), e.g. lesser guitarfish *Acroteriobatus annulatus* reflected the predominantly open estuary mouth with a relatively high 26 species. Freshwater fish (IV) comprised eight species but only three were indigenous, e.g. *Galaxias zebratus*, the rest introduced or translocated, e.g. bass *Micropterus* spp. Three catadromous eels Anguillidae (V) have also been recorded from the Heuningnes catchment and recruit via the estuary. Altogether, including Ia estuarine residents, obligate-dependents and catadromous fish, 17 (24%) of the Heuningnes fish assemblage are completely dependent on estuaries to complete their life-cycle, 20 (28%) are partially estuary-dependent and the remainder split between estuary-independent marine (36%) and freshwater (11%) species.

The proportion of estuary-associated fish in the Heuningnes Estuary fish assemblage is relatively low compared to the Breede, Gouritz and other south-coast estuaries but is an artefact of the high contribution of marine vagrants there. Absolute values of estuary-associated fish either match or exceed all adjacent and nearby systems on the south-coast. Of the Heuningnes fish assemblage, 10 (14%), e.g. *Hyporamphus capensis* and 21 (33%), e.g. *L. lithognathus* are South African and southern African endemics respectively. Five (7%), e.g. *Cyprinus carpio* are introduced alien or translocated species. The remaining 34 (47%), e.g. *Lichia amia*, are cosmopolitan. The high degree of endemism is typical of Cape south coast systems. The Fish conceptual model for Heuningnes is presented in Figure D.6.

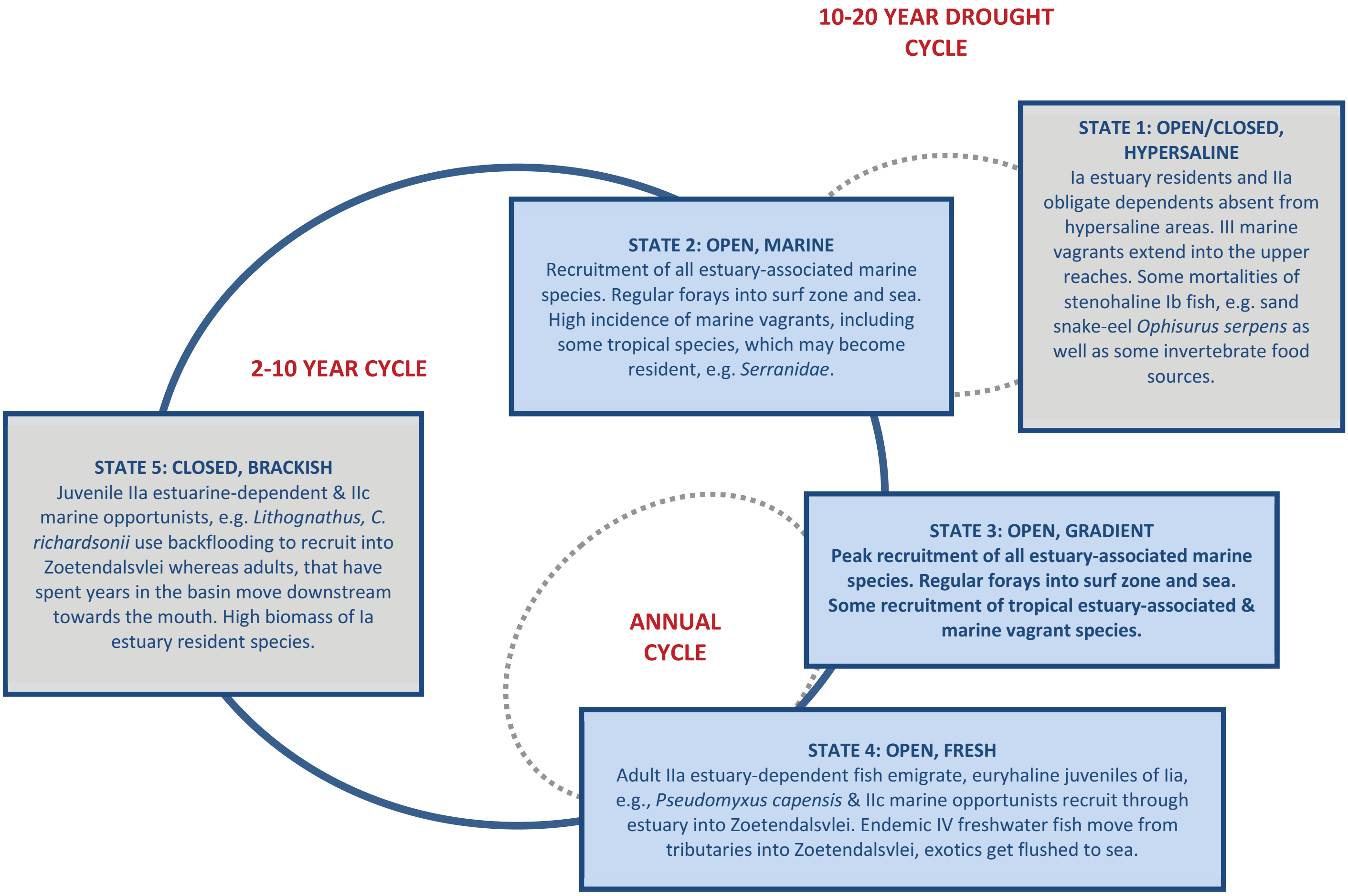


Figure D.6: Heiningnes: Fish Conceptual model

Predicted changes in response to different scenarios are summarised in Table D.18.

Table D.18: Heuningnes: Predicted change in fish under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Species Richness: Decline in survival of recruited estuary-dependent and marine-migrant species. Four alien & translocated species. Reduction in recruitment and emigration due to increased mouth closure. Biomass: Abundance of IIa & b unchanged but 90% decline in that of estuary-dependent species. Arrival of four freshwater alien/translocated species. Much of this is aggravated by illegal gillnet fishery and is difficult to disaggregate. Increased mouth closure increases the chance of fish being caught in the estuary before maturing and being able to return to spawn in the sea Community composition: Community dominated by planktonic filter/selective feeders, fodder fish as opposed to piscivorous and large benthic feeders under reference.
1-3	Closed fresher high-water levels favour estuarine residents *G. aestuaria* and *A. breviceps* but also *Clinus spatulatus* which experiences population booms during closure, bust on opening. Submerged macrophytes increase during closure which also favours these species. Limited recruitment via over-wash but populations of marine opportunists and obligate estuary-dependent species comprise mostly one or two cohorts that recruited during the previous opening. Lower salinity after prolonged closure sees invasion of translocated *Oreochromis mossambicus* (or *O. niloticus* hybrid) and alien fish, e.g. *C. carpio* into the main water body from upstream. Fresh conditions throughout may see some stress and few mortalities in the less euryhaline species. Alternatively, hypersalinity resulting from drought and low flow during closure may see fish kills from osmotic stress once salinity exceeds 45.
4	Hypersalinity resulting from drought and low flow during closure more likely and may see fish kills from osmotic stress once salinity exceeds 45. Endemic Ia fish find refuge in fresher Zone A. Marine opportunists (e.g. *C. richardsonii*) still throughout the system but stressed after salinity > 40, mortalities start after 45. Macrophyte replaced by macroalgal refuge. Benthic burrowing invertebrates nearer

E. TOUW/WILDERNESS

E.1 Predicted Climate Change Scenarios

Predicted climate change scenarios for RCP 4.5 and 8.5 under mid and far future scenarios relevant to the Touw/Wilderness System are presented in Tables E.1 to E.3 for precipitation in the catchment, precipitation in EFZ and ambient atmospheric temperature, respectively. A summary of broad measures of hydrological changes, as reported by Cullis et al. (2015), is provided in Table E.4.

Table E.1: Touw/Wilderness: Predicted change in precipitation in catchment for RCP 4.5 and 8.5 under mid- and far-future scenarios

CATCHMENT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	39	8	2	-13	-17	-13	20	20	-8	17	-16	-9
RCP 4.5 Far	38	21	6	-12	-8	0	-28	19	-23	3	-23	-3
RCP 8.5 Mid	32	27	3	-16	-8	4	-12	31	-27	-11	-10	-1
RCP 8.5 Far	22	-1	4	-2	-1	-8	-6	1	-10	-24	-34	-6

Table E.2: Touw/Wilderness: Predicted change in precipitation in EFZ for RCP 4.5 and 8.5 under mid- and far-future scenarios

ESTUARY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	40	9	-9	-11	-14	-1	19	18	-6	18	-10	1
RCP 4.5 Far	43	16	-1	-20	-11	11	-25	18	-27	1	-22	-10
RCP 8.5 Mid	33	19	-2	-22	-14	11	-13	22	-24	-17	-8	-4
RCP 8.5 Far	29	-1	-1	-10	3	-2	-1	-5	-8	-21	-32	-1

Table E.3: Touw/Wilderness: Predicted increase in ambient atmospheric temperature (°C) for RCP 4.5 and 8.5 under mid- and far-future scenarios

TAve	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	1.6	1.3	1.3	1.6	1.1	1.7	1.4	1.2	1.4	1.5	1.1	1.6
RCP 4.5 Far	2.0	1.7	1.6	1.9	1.3	1.7	2.0	2.1	2.2	2.2	1.4	2.3
RCP 8.5 Mid	1.8	1.5	1.4	2.0	1.5	2.3	2.0	1.7	1.9	2.2	2.0	2.0
RCP 8.5 Far	3.8	3.4	3.5	3.4	3.9	4.0	3.7	3.2	3.5	3.7	3.6	3.5
Tmax	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	1.4	1.1	1.0	1.8	1.0	1.8	1.3	1.1	1.3	1.3	1.0	1.6
RCP 4.5 Far	1.7	1.4	1.2	2.1	1.2	1.8	2.3	1.9	2.4	2.1	1.4	2.4
RCP 8.5 Mid	1.4	1.2	1.1	1.9	1.3	2.4	1.9	1.7	1.9	2.2	1.8	1.8
RCP 8.5 Far	3.4	3.2	3.0	3.2	3.4	3.9	3.7	3.0	3.4	3.7	3.5	3.2
Tmin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	1.8	1.6	1.6	1.4	1.2	1.6	1.5	1.4	1.5	1.7	1.2	1.7
RCP 4.5 Far	2.3	2.0	2.0	1.7	1.3	1.6	1.8	2.3	2.0	2.3	1.5	2.3
RCP 8.5 Mid	2.2	1.8	1.7	2.1	1.7	2.2	2.1	1.7	1.8	2.2	2.2	2.3
RCP 8.5 Far	4.2	3.6	4.0	3.6	4.4	4.0	3.6	3.5	3.7	3.7	3.7	3.8

Table E.4: Touw/Wilderness: Summary of broad measures of hydrological change (as reported by Cullis et al 2015)

PARAMETER	PERCENTAGE CHANGE
Median Flows	-10%
Q 1 (Low flows)	-12 to -15%
Q 3 (Floods)	-5%
Min	-20%
Max	-0

Table E.5 provide a summary of potential change in runoff under RCP 4.5 and 8.5 scenarios for mid and far future conditions.

Table E.5: Touw/Wilderness: Summary of potential change in runoff under RCP 4.5 and 8.5 scenarios for mid and far future conditions

SCENARIO NAME	DESCRIPTION	MAR (x 10^6 m^3)	PERCENTAGE REMAINING
Natural	Reference condition	29.7	100.0
Present	Present	20.7	69.8
Scenario 1	RCP 4.5 Mid	27.2	91.7
Scenario 2	RCP 4.5 Far	24.1	81.4
Scenario 3	RCP 8.5 Mid	22.2	74.7
Scenario 4	RCP 8.5 Far	19.4	65.5

E.1.1 Abiotic Responses

E.1.2 Abiotic states and key characteristics

The characteristic abiotic states (and associated distinctive temporal patterns) for the Touw/Wilderness are illustrated conceptually in Figure E.1.

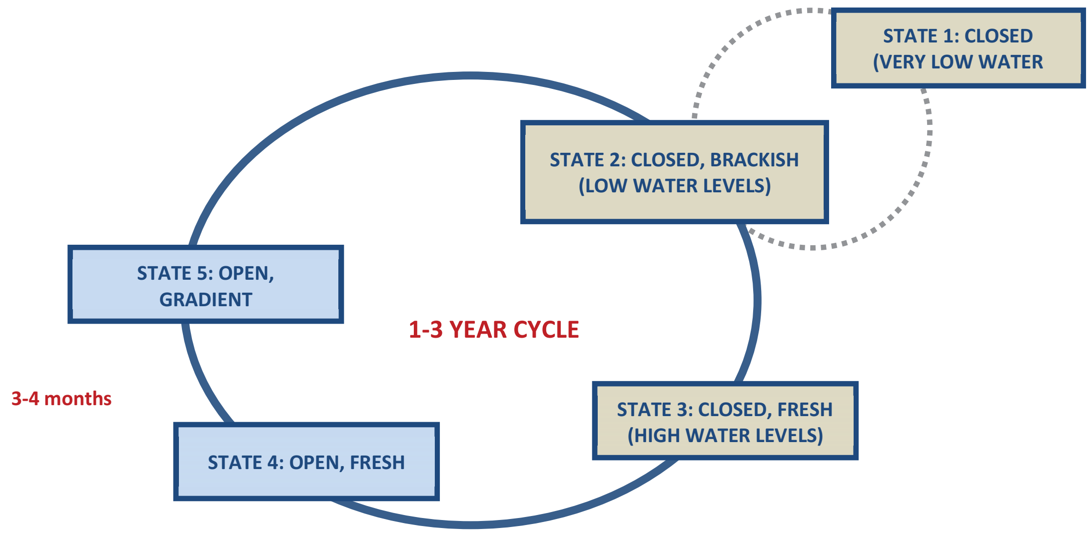


Figure E.1: Touw/Wilderness: Typical temporal patterns in the distribution of abiotic states (present)

On average, the Touw/Wilderness System breaches every 1 to 2 years and remains open between 3 and 4 months after a breaching. During droughts, the estuary can remain closed for longer than two years.

Five abiotic states (Table E.6) have been identified in the Touw/Wilderness Estuary, with *State 1: Closed, marine (very low water level)* associated with drought conditions as reflected in water levels below 1.0 m MSL. Marine influence is detected throughout the system with Touw (Zone A) at 20, Eilandvlei (Zone B) at 12, Langvlei (Zone C) at 10 and Rondevlei (Zone D) at 12 to 15.

During *State 2: Closed, brackish (low water level)* the mouth of the estuary is closed, with water levels between 1.1 and 1.6 m MSL. Salinity brackish throughout the system with Touw (Zone A) and Eilandvlei (Zone B) at 10, Langvlei (Zone C) at 8 and Rondevlei (Zone D) at 10. In *State 3: Closed, fresh (high water levels)* the mouth of the estuary is still closed, with the system at water levels between 1.6 and 2.6 m MSL. Salinity in the Touw (Zone A) is 5, Eilandvlei (Zone B) and Langvlei (Zone C) are 6 and Rondevlei (Zone D) is 8. *State 4: Open, fresh* represents an open mouth state, with the Touw under tidal conditions. Salinity in the Touw (Zone A) is 5, Eilandvlei (Zone B) is 3, Langvlei (Zone C) is 4 and Rondevlei (Zone D) is 6. Lake levels are above mean sea level. While in *State 5: Open, gradient* the system is subjected to tidal action and lower river inflow, resulting in salinity intrusion into the Touw (Zone A) is 20, Eilandvlei (Zone B) is 12, Langvlei (Zone C) is 10 and Rondevlei (Zone D) is 12 to 15. Lake levels are at 1.1 to 1.3 m.

Table E.6: Touw/Wilderness: Key abiotic characteristics associated with various states

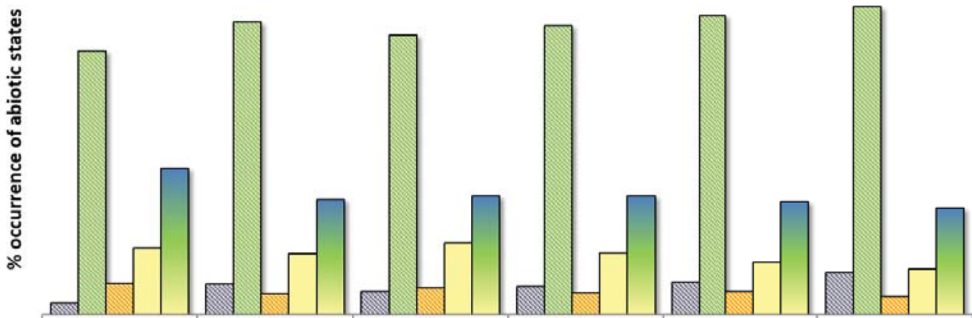
STATE	PARAMETER	ZONE A: LOWER ESTUARY (TOUW)	ZONE B: EILANDVLEI	ZONE C: LANGVLEI	ZONE D: RONDEVLEI
State 1: Closed, marine (very low water level)	WL:	0.8-1.0			
	Salinity:	20	12	10	12-15
	Temp:	Summer: 20-25°C; Winter: 10-20°C			
	WQ: Centre WQ: Peri	NN (2)	NN (2)	NN (2)	NN (2)
State 2: Closed, brackish (low water levels)	WL:	1.1-1.6			
	Salinity:	10	10	8	10
	Temp:	Summer: 20-25°C; Winter: 10-20°C			
	WQ: Centre WQ: Peri	NN (2)	NN (2)	NN (2)	NN (2)
State 3: Closed, fresh (high water levels)	WL:	1.6-2.6			
	Salinity:	5	6	6	8
	Temp:	Summer: 20-25°C; Winter: 10-20°C			
	WQ: Centre WQ: Peri	NN (2)	NN (2)	NN (2)	NN (2)
State 4: Open, fresh	WL:	> 1.3 m (tide 30 cm)			
	Salinity:	5	3	4	6
	Temp:	Summer: 20-25°C; Winter: 10-20°C			
	WQ: Centre WQ: Peri	NN (2)	MM	NN (2)	NN (2)
State 5: Open, gradient	WL:	0-1.3 m (tide 30 cm)			
	Salinity:	25	5	6	8
	Temp:	Summer: 20-25°C (lower temperatures possible in lower estuary linked to upwelling); Winter: 10-20°C			
	WQ: Centre WQ: Peri	NN (1)	MM)	NN (2)	NN (2)

As expected for near-pristine black water systems the lower estuary (Touw) is generally low in nutrients. This is also expected given the low inorganic nutrient concentrations entering from the Touw catchment, and fairly low-density development along the estuary banks. Note that upwelling at sea, can naturally elevate inorganic nutrients in the lower estuary when the mouth is open during summer (300 µg/ℓ). Vertical stratification is expected to occur naturally in the sheltered deeper parts of the lower estuary resulting in lower sub-surface dissolved oxygen levels. However, this would also have occurred naturally and may not necessarily be as a result of anthropogenic enrichment (DWA 2014).

Despite extensive agricultural activities in the Duiwe River, nutrient concentrations in Eilandvlei are found to be generally low, probably indicative of the river system still able to assimilate excessive nutrient input from the catchment before reaching the lake. In the lakes, the main component of DIN comprises NH_4-N, with concentrations in Rondevlei being the highest. Considering poor flushing of the lakes, organic build-up stimulates *in situ* remineralisation, explaining the NH_4-N concentrations observed in the shallower periphery of the Wilderness Lakes (DWA 2014; Taljaard et al. 2018). Currently, nutrients generated in the littoral zones are utilised within this zone and do not exchange to the deeper central waters. However, it is possible that organic stock build-up (e.g. loading from catchment) may cause excessive nutrient regeneration, spilling over into the deeper section of these lakes in future. The shallow lakes systems are generally well-oxygenated, although supersaturation during the day – and possibly hypoxia at night – has been observed in the rooted macrophyte beds along the northern shores of Langvlei. Lower dissolved oxygen has also been recorded in the shallow connecting channel between lakes, associated with high organic loading (visual observations) and the sheltered nature of these channels. A wide-spread low oxygen event recorded in Rondevlei on occasion was associated with the senescence of an algal (dinoflagellate) bloom (Russell, 1994).

E.1.3 Responses to climate change scenarios

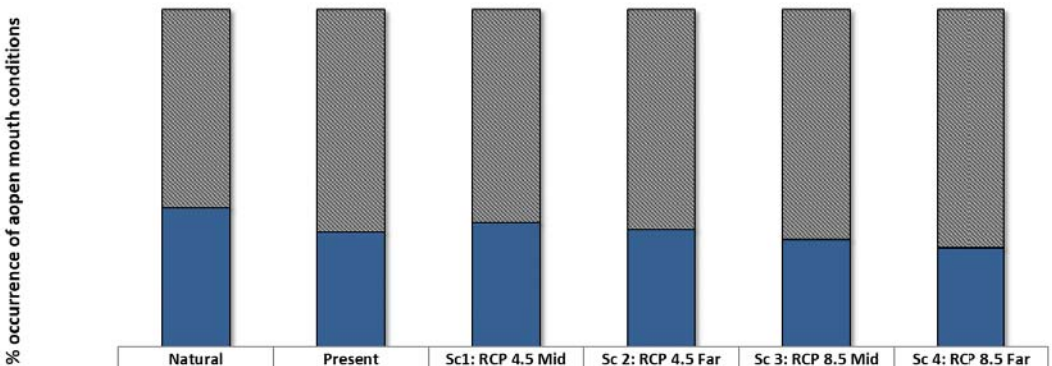
The Touw/Wilderness Estuary responds to river flow in all its variability. Breaching is dependent on the inflow, while the duration of the open period responds to the breaching level and occurrence of higher flow event post-breaching. Predicted changes in hydrodynamic functioning, average water level, salinity and marine connectivity are captured in the overall occurrence of different abiotic states in the Touw/Wilderness estuary are summarised in Figure E.2.



	Natural	Present	Sc1: RCP 4.5 Mid	Sc 2: RCP 4.5 Far	Sc 3: RCP 8.5 Mid	Sc 4: RCP 8.5 Far
State 1: Closed (Very LW level)	2.2	5.8	4.4	5.5	6.3	8.0
State 2: Closed brackish (LW level)	50.9	56.4	53.9	55.8	57.6	59.3
State 3: Closed Fresh (HW level)	6.0	4.0	5.1	4.2	4.4	3.5
State 4: Open Fresh	12.8	11.7	13.8	11.8	10.0	8.7
State 5: Open gradient	28.2	22.1	22.9	22.8	21.7	20.4

Figure E.2: Touw/Wilderness: Occurrence of different abiotic states under different scenarios

Mouth conditions showed some sensitivity to the changes in river flow to the estuary (Figure E.3 and Table E.7). Under Scenario 1 and 2 there is a slight increase in open mouth conditions around August to November, while under Scenario 3 and 4 the mouth of the estuary will be less open than under the current conditions. Scenario 4 showed the most decline in open conditions from the present.



	Natural	Present	Sc1: RCP 4.5 Mid	Sc 2: RCP 4.5 Far	Sc 3: RCP 8.5 Mid	Sc 4: RCP 8.5 Far
Closed	59.0	66.2	63.3	65.4	68.3	70.8
Open	41.0	33.8	36.7	34.6	31.7	29.2

Figure E.3: Touw/Wilderness: Overall occurrence of open mouth conditions (expressed as % open) under different scenarios

Table E.7: Touw/Wilderness: Estimated percentage time that estuary is connected to sea under different scenarios (darker colours indicate high connectivity and light colours low connectivity)

WILDERNESS:	PRESENT				SCENARIO 1				SCENARIO 2				SCENARIO 3				SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (84 YEAR SIMULATION PERIOD)																				
January	31	31	31	31	33	33	33	33	31	31	31	31	31	31	31	31	28	28	28	28
February	26	26	26	26	29	29	29	29	26	26	26	26	25	25	25	25	25	25	25	25
March	52	52	52	52	53	53	53	53	53	53	53	53	49	49	49	49	47	47	47	47
April	32	32	32	32	28	28	28	28	28	28	28	28	27	27	27	27	27	27	27	27
May	27	27	27	27	24	24	24	24	28	28	28	28	25	25	25	25	22	22	22	22
June	13	13	13	13	13	13	13	13	18	18	18	18	13	13	13	13	11	11	11	11
July	26	26	26	26	28	28	28	28	21	21	21	21	24	24	24	24	24	24	24	24
August	38	38	38	38	41	41	41	41	38	38	38	38	32	32	32	32	29	29	29	29
September	40	40	40	40	41	41	41	41	34	34	34	34	33	33	33	33	34	34	34	34
October	47	47	47	47	49	49	49	49	47	47	47	47	44	44	44	44	42	42	42	42
November	41	41	41	41	38	38	38	38	35	35	35	35	41	41	41	41	34	34	34	34
December	33	33	33	33	34	34	34	34	34	34	34	34	32	32	32	32	25	25	25	25
PERCENTILE DISTRIBUTION (80 YEAR SIMULATION PERIOD)																				
99%ile	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
95%ile	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
90%ile	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
80%ile	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
70%ile	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	C	C	C	C
60%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
50%ile (median)	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
40%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
30%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
20%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
10%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
1%ile	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C

Average water levels increase slightly under the future scenario 1 and 2, and decrease slightly under Scenarios 4. What is notable is the increase in the State 1: Closed (Very low water levels) that is associated with drought conditions which occur nearly four times more frequently than under natural conditions and about 25% more than at present. A broad summary is provided below in Table E.8.

Table E.8: Touw/Wilderness: Predicted water level (m) under Present State and Future Climate Change Scenarios

WILDERNESS:	PRESENT				SCENARIO 1				SCENARIO 2				SCENARIO 3				SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (85 YEAR SIMULATION PERIOD)																				
January	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3
February	1.2	1.4	1.4	1.4	1.2	1.4	1.4	1.4	1.2	1.4	1.4	1.4	1.2	1.4	1.4	1.4	1.2	1.3	1.3	1.3
March	1.0	1.3	1.3	1.3	1.1	1.3	1.3	1.3	1.0	1.3	1.3	1.3	1.1	1.3	1.3	1.3	1.1	1.3	1.3	1.3
April	1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.2	1.4	1.4	1.4	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3
May	1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.2	1.3	1.3	1.3	1.2	1.4	1.4	1.4	1.2	1.3	1.3	1.3
June	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.3	1.3	1.3	1.3
July	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3
August	1.1	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3
September	1.1	1.3	1.3	1.3	1.2	1.4	1.4	1.4	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.1	1.3	1.3	1.3
October	1.1	1.3	1.3	1.3	1.1	1.3	1.3	1.3	1.1	1.3	1.3	1.3	1.1	1.3	1.3	1.3	1.1	1.3	1.3	1.3
November	1.1	1.3	1.3	1.3	1.1	1.3	1.3	1.3	1.2	1.4	1.4	1.4	1.1	1.3	1.3	1.3	1.1	1.3	1.3	1.3
December	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.3	1.3
PERCENTILE DISTRIBUTION (85 YEAR SIMULATION PERIOD)																				
99%ile	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
95%ile	1.4	1.5	1.5	1.5	2.2	2.2	2.2	2.2	1.4	1.5	1.5	1.5	1.4	1.5	1.5	1.5	1.4	1.5	1.5	1.5
90%ile	1.4	1.5	1.5	1.5	1.4	1.5	1.5	1.5	1.4	1.5	1.5	1.5	1.4	1.5	1.5	1.5	1.4	1.5	1.5	1.5
80%ile	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
70%ile	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
60%ile	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
50%ile (median)	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
40%ile	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
30%ile	0.8	1.4	1.4	1.4	0.8	1.4	1.4	1.4	0.8	1.4	1.4	1.4	0.8	1.4	1.4	1.4	0.8	1.4	1.4	1.4
20%ile	0.8	1.0	1.0	1.0	0.8	1.0	1.0	1.0	0.8	1.0	1.0	1.0	0.8	1.0	1.0	1.0	0.8	1.0	1.0	1.0
10%ile	0.6	1.0	1.0	1.0	0.6	1.0	1.0	1.0	0.6	1.0	1.0	1.0	0.8	1.0	1.0	1.0	0.8	1.0	1.0	1.0
1%ile	0.6	0.8	0.8	0.8	0.6	0.8	0.8	0.8	0.6	0.8	0.8	0.8	0.6	0.8	0.8	0.8	0.6	0.8	0.8	0.8

Salinity regimes under Scenario 1 to 4 are very similar to the present. There is a slight decrease in salinity under Scenarios 1 and 2, while Scenarios 3 and 4 show a slight increase. In most scenarios the decrease in State 4: Open Fresh is offset by an increase in State 2: Closed Brackish (Low water levels). A summary of the result is presented in Table E.9.

Table E.9: Touw/Wilderness: Predicted salinity under Present State and Future Climate Change Scenarios

WILDERNESS:	PRESENT				SCENARIO 1				SCENARIO 2				SCENARIO 3				SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (85 YEAR SIMULATION PERIOD)																				
January	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
February	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
March	14	7	7	9	14	7	6	9	15	7	7	9	14	7	7	9	14	7	7	9
April	13	8	7	9	12	8	7	9	13	8	7	9	13	8	7	9	13	9	7	10
May	13	8	7	9	12	9	7	10	13	8	7	9	12	8	7	10	13	9	8	10
June	12	9	8	10	12	9	8	10	13	9	8	10	12	9	8	10	12	10	8	10
July	14	9	8	10	13	8	7	10	14	9	8	10	14	9	8	10	14	9	8	10
August	14	8	7	9	14	7	7	9	14	8	7	9	13	8	7	9	13	8	7	10
September	14	8	7	9	13	7	7	9	14	8	7	9	14	8	7	9	14	8	7	10
October	13	7	7	9	13	7	7	9	13	7	7	9	13	7	7	9	14	8	7	9
November	13	8	7	9	12	8	7	9	12	8	7	9	13	8	7	9	14	8	7	10
December	13	8	7	9	13	8	7	9	13	8	7	9	14	8	7	9	13	9	7	10
PERCENTILE DISTRIBUTION (85 YEAR SIMULATION PERIOD)																				
99%ile	25	12	10	15	25	12	10	15	25	12	10	15	25	12	10	15	25	12	10	15
95%ile	25	12	10	15	25	10	8	10	25	12	10	15	25	12	10	15	25	12	10	15
90%ile	25	10	8	10	25	10	8	10	25	10	8	10	25	10	8	10	25	10	8	10
80%ile	25	10	8	10	25	10	8	10	25	10	8	10	25	10	8	10	25	10	8	10
70%ile	10	10	8	10	10	10	8	10	10	10	8	10	10	10	8	10	10	10	8	10
60%ile	10	10	8	10	10	10	8	10	10	10	8	10	10	10	8	10	10	10	8	10
50%ile (median)	10	10	8	10	10	10	8	10	10	10	8	10	10	10	8	10	10	10	8	10
40%ile	10	10	8	10	10	10	8	10	10	10	8	10	10	10	8	10	10	10	8	10
30%ile	10	5	6	8	10	5	6	8	10	5	6	8	10	5	6	8	10	6	6	8
20%ile	10	5	6	8	10	5	6	8	10	5	6	8	10	5	6	8	10	5	6	8
10%ile	5	3	4	6	5	3	4	6	5	3	4	6	5	5	6	8	5	5	6	8
1%ile	5	3	4	6	5	3	4	6	5	3	4	6	5	3	4	6	5	3	4	6

Predicted changes in seasonal and percentile distribution of water quality under present and future Climate Change scenarios are provided in Table E.10. Present water quality in the Touw/Wilderness system is mostly still in a near-natural state, except Zone B (Eilandvlei) which received nutrient-enriched runoff from the Duiwe River during high flow. As a result, slight reduction in freshwater flows predicted under the future Climate Change Scenarios is expected to result in a slight improvement in this zone, especially during Scenario 4.

Table E.10: Touw/Wilderness: Predicted water quality under Present State and Future Climate Change Scenarios

WILDERNESS: PRESENT					WILDERNESS: SCENARIO 1				WILDERNESS: SCENARIO 2				WILDERNESS: SCENARIO 3				WILDERNESS: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																				
January	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
February	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
March	2	3	2	2	2	3	2	2	2	3	2	2	2	2	2	2	2	2	2	2
April	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
May	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
June	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
July	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
August	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
September	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
October	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
November	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
December	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																				
95%ile	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2
90%ile	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2
80%ile	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2
70%ile	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2	2	2	2	2
60%ile	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
50%ile (median)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
40%ile	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
30%ile	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
20%ile	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2
10%ile	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2

E.2 Biotic Responses

E.2.1 Microalgae

The conceptual model for microalgal characteristics under different abiotic scenarios is illustrated in Figure E.4, while the microalgal characteristics associated with different zone are summarised in Table E.11.

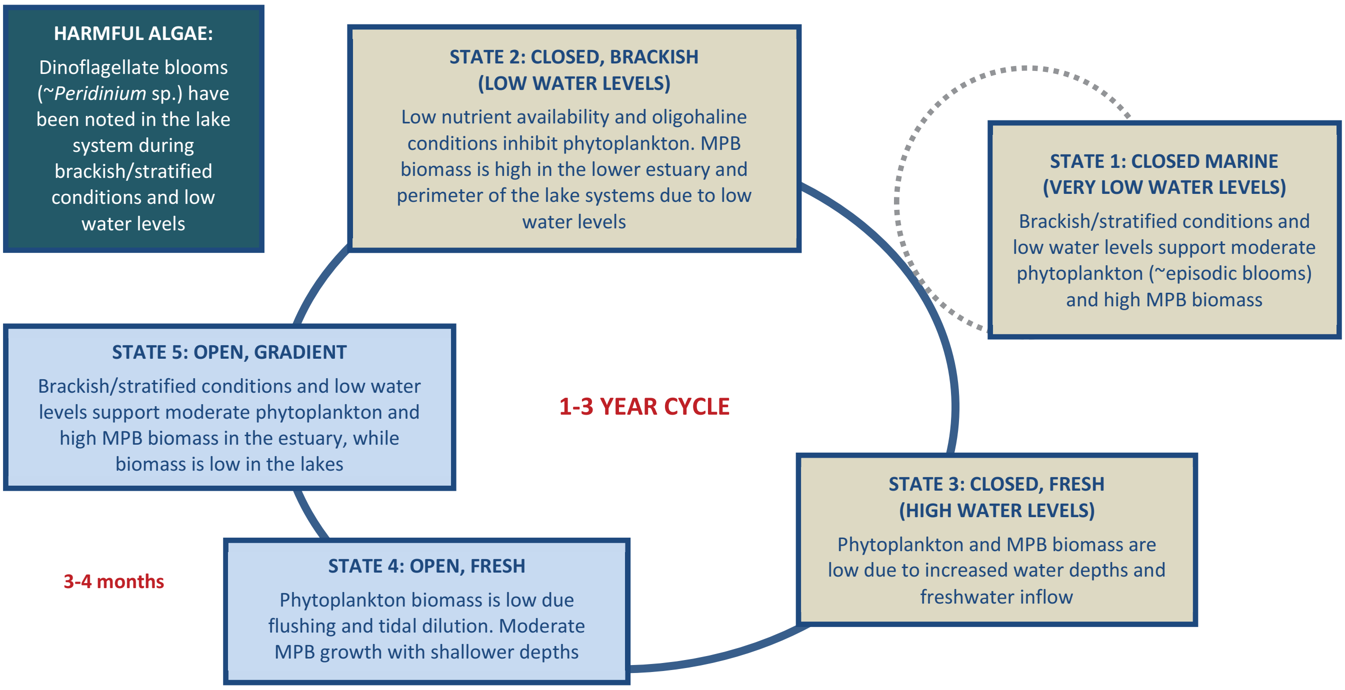


Figure E.4 Touw/Wilderness: Microalgae Conceptual model

Phytoplankton biomass concentrations in the Touw/Wilderness system are characteristic of oligotrophic conditions (~Good: < 5 µg/ℓ) (DWS, 2014). However, brackish/stratified conditions and reduced lake levels (~State 1 and 5) have been shown to support increased phytoplankton biomass (~Fair: ≥ 5 but < 20 µg/ℓ), with stochastic bloom events (~Poor: ≥ 20 but < 60 µg/ℓ) even being recorded in Rondevlei (Zone D) during State 1. Cryptophyceae, Dinophyceae (dinoflagellates) and Chlorodendrophyceae are typically dominant during these brackish and stratified conditions (Zone A-D), while a shift towards Chlorophyceae (greens), Euglenophyceae and Cyanophyceae (cyanobacteria) is expected during more oligohaline conditions (State 2-4). Benthic microalgal biomass has been documented to be exceedingly high (~Very Poor: ≥ 150 mg/m^2) in the lower estuary (Zone A) of the system during open mouth conditions and reduced water levels (State 1, 2 and 5). Similarly, despite a lack of data, benthic microalgal biomass would be expected to be high (~Poor: ≥ 100 but < 150 mg/m) along the perimeter of the lake systems during low water levels (State 1 and 2). The only documented blooms of harmful algae occurred in the 1990s in Rondevlei, in which a dinoflagellate bloom triggered hypoxic conditions that culminated in a mass fish kill (Russell 1994). Additionally, dinoflagellates (e.g. *Peridinium* sp.) have been shown to dominate the spring/summer phytoplankton community (Van Ginkel and Hohls 2001) and, thus, harmful algal blooms may become more prevalent in the system with climate change (~eutrophication and drought [State 1]).

Table E.11: Touw/Wilderness: Key microalgal characteristics associated with various states

STATE	PARAMETER	ZONE A: LOWER ESTUARY (TOUW)	ZONE B: EILANDVLEI	ZONE C: LANGVLEI	ZONE D: RONDEVLEI
State 1: Closed, marine (very low water level)	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				
State 2: Closed, brackish (low water levels)	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				
State 3: Closed, fresh (high water levels)	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				
State 4: Open, fresh	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				
State 5: Open, gradient	Phytoplankton:				
	Benthic microalgae:				
	Harmful algae:				

Confidence levels: Phytoplankton – High; Benthic microalgae – Medium; Harmful algae – Medium.

A summary of the key responses in microalgae under the Present State and Future Climate Change scenarios are summarized in Table E.12. Predicted changes in seasonal and percentile distribution of microalgae under present and future Climate Change scenarios are provided in Tables E.13 to E.15.

Table E.12: Touw/Wilderness: Predicted change in microalgae under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Phytoplankton growth and the presence of HAB species are typical of oligotrophic environments (i.e. low). However, phytoplankton blooms (including HABs) have been reported during brackish/stratified conditions and low water levels in the lake systems (particularly Zone C and D). Additionally, benthic microalgal growth has increased compared to natural, particularly in Zone A during open mouth conditions and reduced water levels.
1	The increase in open mouth conditions and freshwater inflow are likely to inhibit the presence of any HAB species and reduce benthic microalgal biomass.
2-3	Scenarios 2-3 are very similar to the present and microalgal scores remain the same as present.
4	Increased temperature and periods of mouth closure (i.e. reduced freshwater inflow during drought periods) are expected to increase phytoplankton biomass throughout the system, with HABs being more prevalent in brackish/stratified conditions (e.g. dinoflagellates).

Table E.13: Touw/Wilderness: Predicted Phytoplankton under Present State and Future Climate Change Scenarios

	WILDERNESS: PRESENT				WILDERNESS: SCENARIO 1				WILDERNESS: SCENARIO 2				WILDERNESS: SCENARIO 3				WILDERNESS: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																				
January	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	2	2	3
February	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
March	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	2	2	3
April	1	1	1	2	1	1	1	1	1	1	1	2	1	1	1	2	2	2	2	2
May	1	1	1	2	1	1	1	1	2	1	2	2	1	1	1	2	2	2	2	2
June	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	2	2	2	2
July	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	2	2	3
August	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	2	2	2
September	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	2	2	3
October	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	2	2	2
November	2	1	2	2	1	1	1	2	1	1	1	2	2	1	2	2	2	2	2	2
December	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	2	2	2
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																				
95%ile	3	2	3	4	3	2	3	3	3	2	3	4	3	2	3	4	3	3	3	4
90%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	3	3	4
80%ile	3	2	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3	3	3	4
70%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
60%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
50%ile (median)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
40%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
30%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
20%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
10%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table E.14: Touw/Wilderness: Predicted Benthic microalgae under Present State and Future Climate Change Scenarios

	WILDERNESS: PRESENT				WILDERNESS: SCENARIO 1				WILDERNESS: SCENARIO 2				WILDERNESS: SCENARIO 3				WILDERNESS: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																				
January	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	4	3	3
February	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3
March	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	4	3	3
April	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	4	3	3
May	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3
June	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3
July	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	4	3	3
August	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	4	3	3
September	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	4	3	3
October	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	4	3	3
November	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	4	3	3
December	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	4	3	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																				
95%ile	5	4	4	4	5	4	4	4	5	4	4	4	5	4	4	4	5	5	5	5
90%ile	5	4	4	4	5	4	4	4	5	4	4	4	5	4	4	4	5	5	4	4
80%ile	5	4	4	4	5	4	4	4	5	4	4	4	5	4	4	4	5	5	4	4
70%ile	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3
60%ile	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3
50%ile (median)	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3
40%ile	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3
30%ile	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3
20%ile	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3	4	3	3	3
10%ile	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Table E.15: Touw/Wilderness: Predicted Harmful algae under Present State and Future Climate Change Scenarios

	WILDERNESS: PRESENT				WILDERNESS: SCENARIO 1				WILDERNESS: SCENARIO 2				WILDERNESS: SCENARIO 3				WILDERNESS: SCENARIO 4			
	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D	Zone A	Zone B	Zone C	Zone D
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																				
January	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	2	1	2	2
February	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
March	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	2	1	2	2
April	1	1	1	2	1	1	1	1	1	1	1	2	1	1	1	2	2	1	2	2
May	1	1	1	2	1	1	1	1	1	1	2	2	1	1	1	2	1	1	1	2
June	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2
July	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	2	1	2	2
August	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	2	1	2	2
September	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	2	1	2	2
October	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	2	1	2	2
November	1	1	2	2	1	1	1	2	1	1	1	2	1	1	2	2	2	1	2	2
December	1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	2	1	2	2
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																				
95%ile	2	1	3	4	2	1	3	3	2	1	3	4	2	1	3	4	3	2	3	4
90%ile	2	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	3	2	3	4
80%ile	2	1	3	3	2	1	3	3	2	1	3	3	2	1	3	3	3	2	3	4
70%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
60%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
50%ile (median)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
40%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
30%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10%ile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

E.2.2 Macrophytes

Reeds and sedges are dominant in the Wilderness system with smaller areas of salt marsh and submerged macrophytes. Reed growth is limited by 2 m depth and sedimentation, water level, nutrients and salinity influence their abundance and distribution. The two main species are *Phragmites australis* and *Schoenoplectus scirpoideus*. Other recorded sedge species are *Bolboschoenus maritimus* and *Typha capensis* (Russell 2003; DWS 2014). During dry periods reeds flourish and expand. Reed growth (*Phragmites, Typha* and *Schoenoplectus*) has increased over the last few decades as a result of anthropogenic influence.

Artificial breaching policies have led to the stabilisation of water level in the lakes encouraging their expansion. This has occurred at the expense of *Juncus kraussii* (Russell 2003). Submerged macrophytes are represented by *Stuckenia pectinata and Chara globularis* within the fresh to brackish regions (< 15) as well as *Ruppia cirrhosa* and *Zostera capensis* with species composition and abundance are determined by salinity, light, depth and water velocity (DWS 2014). *Zostera* occurs in salinity of 15 to 35 and tolerant of wave action and exposure, *Ruppia cirrhosa* up to 45, *Stuckenia pectinata* and Charophytes up to 15. *Ruppia* and *Stuckenia* prefer more sheltered sites. *Ruppia* has a very delicate, shallow root system making it sensitive to turbulence. Decreased water transparency due to sedimentation can result in major dieback of submerged macrophytes. Charophyta and filamentous algae such as *Enteromorpha* (*Ulva* spp.) are also abundant. Macroalgae occur in response to nutrient pulses and calm closed mouth conditions. Salt marsh is present in the lower estuarine zone with species such as *Sarcocornia* spp. and *Cotula coronopifolia* present. *Juncus kraussii* occurs on higher elevations. The macrophyte conceptual model for Touw/Wilderness is presented in Figure E.5.

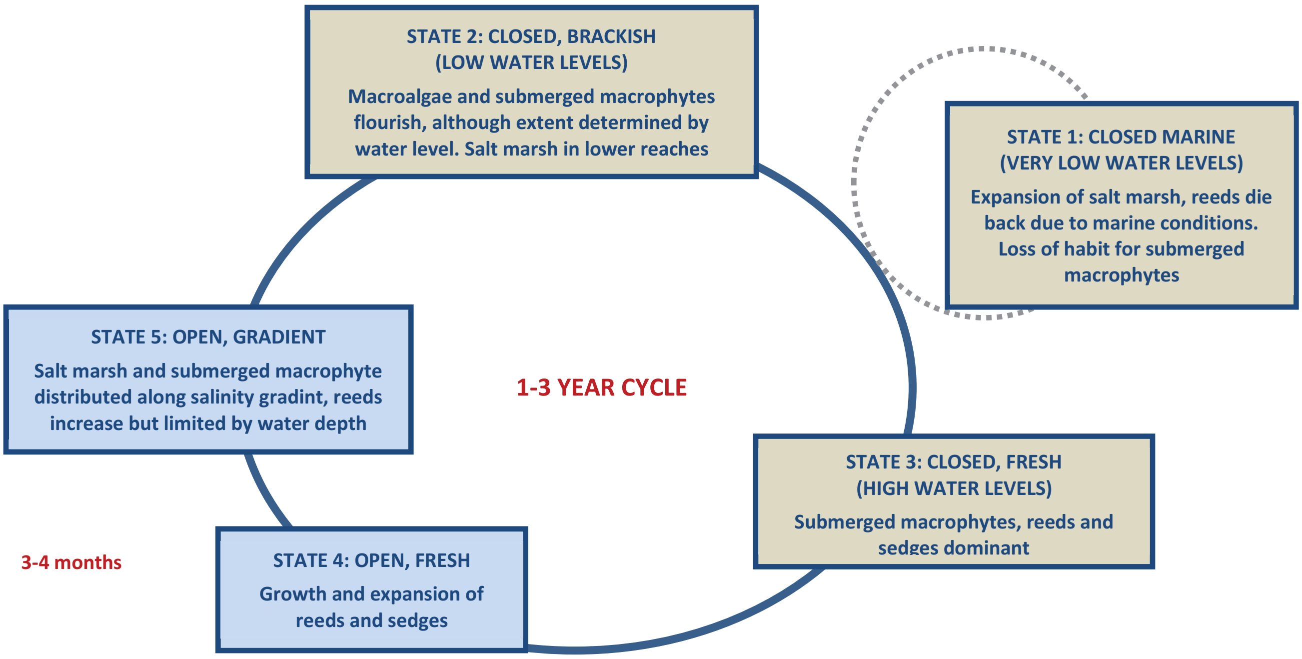


Figure E.5: Touw/Wilderness: Macrophyte Conceptual model

State 2 – Closed, brackish, water level 1.5 m MSL (1 Nov 2018)

State 3 – Closed, fresh, water level 1.7 m MSL (11 April 2018)

State 1 – Open marine, water level < 1 m MSL (13 April 2005)

Responses of Macrophytes to different scenarios are illustrated in Table E.16.

Table E.16: Touw/Wilderness: Predicted macrophyte responses under Present State and Future Climate Change Scenarios (score in brackets)

SCENARIO	SUMMARY OF CHANGES
Present	There has been an increase in reed area at the expense of open water area. Some loss of overall habitat due to development and bank stabilisation. The mouth is currently closed for 59% of the time compared to 41% for natural. Weighted score: 78 (Estuary: 70/Lakes: 80)
1	The small increase in open mouth conditions would create intertidal habitat and salt marsh growth. However, this habitat is not common in the lower reaches indicating the fresh perched estuary conditions and sediment accumulation due to artificial mouth breaching.
2-3	Scenarios 2-3 are very similar to the present and macrophyte condition and scores remain the same as present.
4	Decrease in freshwater inflow will result in extended mouth closure (70.8% of the time) leading to inundation and die-back of salt marsh, reeds and sedges. Closed mouth conditions, longer water

SCENARIO	SUMMARY OF CHANGES
	retention times and an increase in temperature will promote macroalgal growth. Submerged macrophytes would also grow and expand under these conditions particularly in the lake sections (Zones B,C,D).

E.2.3 Fish

(Hall et al. 1987) recorded a total of 32 species from 18 families for the Touw/Wilderness system. Since then, work by Russell (1996) has looked at changes in fish abundance relative to various environmental factors (recording 14 species from 8 families) whilst Olds (2012) investigated the spatial and temporal abundance and distribution of native and alien fish within the system. The two studies recorded 26 species from 18 families. During a once-off sampling of the Touw recorded 18 species from 11 families (James and Harrison, 2008), whilst seine net sampling in 2014 (DWS 2014) resulted in 18 species from ten families being recorded.

Overall the Touw/Wilderness Lakes system ichthyofauna comprises fishes in all but one (pure marine – category III) of Whitfield's (2019) estuarine categories, the majority falling within the marine migratory component with small proportions of native estuarine species, catadromous and alien freshwater species. Estuarine resident species that spawn only within estuaries (Ia) are represented by one species whilst resident species spawning both in estuaries and nearshore marine environments (Ib) are represented by seven species. Obligate estuary dependent species (IIa) comprise nine species with four partially estuary dependent fish species (IIb and IIc). Catadromous species comprise the longfin eel (*Anguilla mossambica*) and the facultative catadromous freshwater mullet (*Myxus capensis*). Of the four freshwater species found within the system, none are endemic, and all are classified as alien invasive. In describing the fish community throughout the system Olds (2012) showed that the proportion of species in each estuarine category was independent of sampling area but the relative biomass of species in each estuarine group showed significant spatial variation throughout the system.

Native estuarine species contributed between 15% and 21% in each of the lakes and the Touw (highest in the Touw and Rondevlei) and euryhaline marine species contributed between 29% (Langvlei) and 66% (Eilandvlei). Rondevlei had the highest biomass (20%) of catadromous species and Touw the lowest biomass (2.2%) whilst alien species dominated within Langvlei (52%). Overall, there is a high degree of estuarine dependency with 85% of the fish assemblage comprising fish species that are either partially or completely dependent on estuaries (DWS 2014). The Touw and Eilandvlei held the highest number of species indicating that these areas form the major nursery areas of the system. There were slight variations between studies but overall Mugilidae (5 species), Sparidae (2 to 5 species) and Gobidae (2 to 4 species) were the most important families represented. Numerically, *Atherina breviceps* (60%) and *Gilchristella aestuaria* (38.6%) dominated the fish assemblage in the Touw. The fish conceptual model for Touw/Wilderness is presented in Figure E.6.

Responses of fish to different scenarios are illustrated in Table E.17.

Table E.17: Touw/Wilderness: Predicted change in fish under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Recruitment potential has decreased. Rising water levels provide increased habitat for juveniles as feeding and refugia areas, however, this also provides more ideal habitat preferences for alien invasive species (in particular *G. affinis* and *C. carpio*). A decrease in salinity provides a more ideal condition for alien invasive species. Reversed salinity gradient up the lakes may become more pronounced leading to movement of adult euryhaline marine species up into Rondevlei – these adults seem to remain in this lake and do not migrate back out. Low DO in the channels will limit movement and recruitment of adult and juvenile fish through the system. Microalgae Increase in benthic microalgae will benefit in particular mugillids. Diversity indices between 1985 and 2012 very similar for Rondevlei, Langvlei and Island Lake but fewer species were sampled in Serpentine. An increase in the number of alien invasive species and an increase in the biomass of alien species (in particular *O. mossambicus* within Langvlei). Obstructions in the interconnecting channels limit recruitment past Eilandvlei and the contribution of euryhaline marine species within Langvlei and Rondevlei has

SCENARIO	SUMMARY OF CHANGES
	decreased. Possible increase in estuarine shoaling species (*G. aesturia*, *A. breviceps* and also Cape halfbeak (Hyporhamphus capensis). A general reduction in the abundance of euryhaline marine specie Species richness: Three alien invasive freshwater species (*C. carpio, O. mossambicus and G. affinis*). Decrease in large estuarine-dependent (A. japonicus) and other euryhaline marine species (*D. capensis, Rhabdosargus sarba* and *Sarpa salpa*). Estuary dominated by estuarine shoaling species (*G. aesturia* & *A. breviceps*). Total species (excluding alien invasive freshwater species) decreased from 23 to 17 between 1983 and 2012 (extensive surveys). Abundance: Decrease in abundance of large euryhaline species. Possible increase in small-bodied shoaling species and a decrease in the contribution of Mugilidae species (in particular *Myxus capensis*). Increase in abundance of freshwater alien species. Community composition: REI fish component distributed throughout the estuary (closed phase) with an increase in contribution to overall fish assemblage in terms of numbers and mass. Decrease in large euryhaline marine species in particular large piscivorous predators – upper trophic levels depleted by overfishing throughout the coast.
1-3	Closed fresher high-water levels favour estuarine residents *G. aestuaria* and *A. breviceps* but also *Clinus spatulatus* which experiences population booms during closure, bust on opening. Submerged macrophytes increase during closure which also favour these species. Limited recruitment via over-wash but populations of marine opportunists and obligate estuary-dependent species comprise mostly one or two cohorts that recruited during the previous opening. Synchronised mouth opening events and genetic exchange between Swartvlei and Touw/Wilderness estuary-residents becomes more limited. Lower salinity after prolonged closure sees the invasion of translocated *Oreochromis mossambicus* (or *O. niloticus* hybrid) and alien fish, e.g. *C. carpio* into the main water body from upstream. Fresh conditions throughout may see some stress and few mortalities in the less euryhaline species. Alternatively, hypersalinity resulting from drought and low flow during closure may see fish kills from osmotic stress once salinity exceeds 45.
4	Endemic Ia fish find refuge in fresher Zone A. Marine opportunists (e.g. *C. richardsonii*) still throughout the system but stressed after salinity > 40, mortalities start after 45. Macrophyte replaced by macroalgal refuge. Benthic burrowing invertebrates nearer

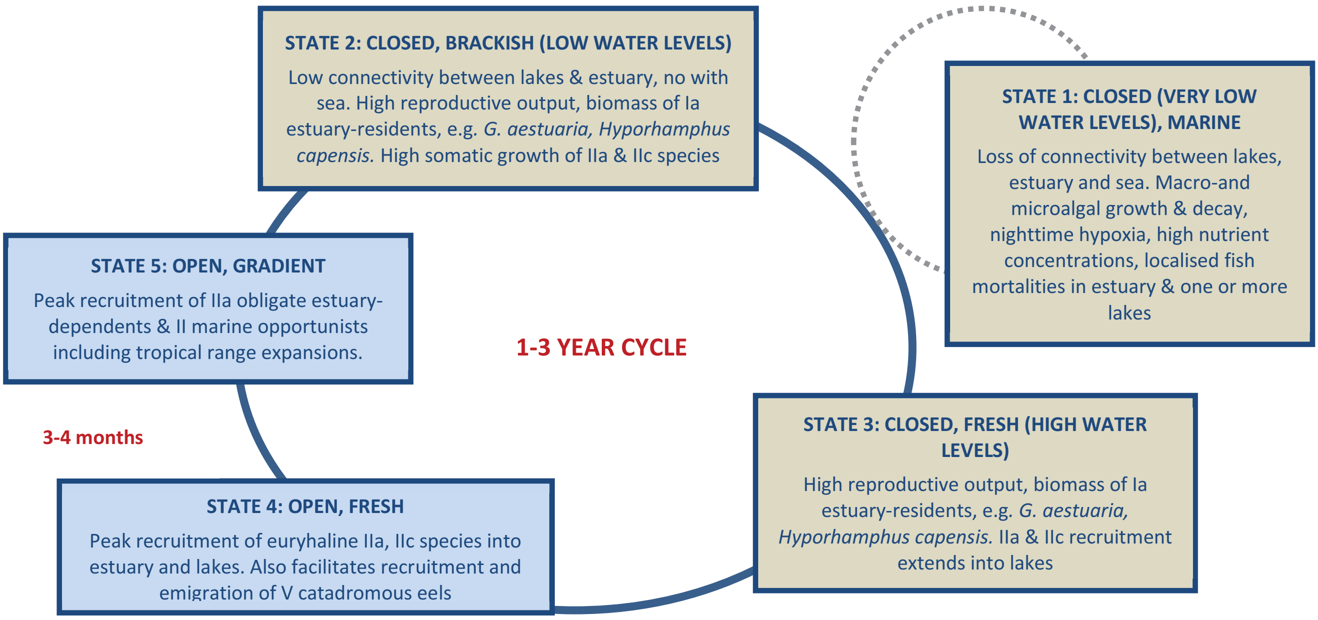


Figure E.6 Touw/Wilderness: Fish Conceptual model

F. SWARTVLEI

F.1 Predicted Climate Change Scenarios

Predicted climate change scenarios for RCP 4.5 and 8.5 under mid and far future scenarios relevant to the Swartvlei, are presented in Tables F.1 to F.3 for precipitation in the catchment, precipitation in EFZ and ambient atmospheric temperature, respectively. A summary of broad measures of hydrological changes, as reported by Cullis et al. (2015), is provided in Table F.4.

Table F.1: Swartvlei: Predicted change in precipitation in the catchment for RCP 4.5 and 8.5 under mid- and far-future scenarios

CATCHMENT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	31	1	7	-15	-18	-11	19	9	-5	16	-19	-7
RCP 4.5 Far	32	12	16	-13	-9	-2	-23	9	-26	1	-21	-4
RCP 8.5 Mid	23	13	4	-19	-11	2	-9	15	-27	-12	-13	1
RCP 8.5 Far	11	-11	4	-3	3	-13	-10	-6	-13	-24	-35	-6

Table F.2: Swartvlei: Predicted change in precipitation in EFZ for RCP 4.5 and 8.5 under mid- and far-future scenarios

ESTUARY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	34	1	4	-18	-12	-7	17	16	-5	19	-15	1
RCP 4.5 Far	34	9	8	-19	-9	-2	-21	11	-30	0	-20	-11
RCP 8.5 Mid	25	9	-2	-21	-14	3	-14	19	-27	-17	-11	1
RCP 8.5 Far	21	-5	3	-12	5	-10	-4	-5	-14	-21	-32	-3

Table F.3: Swartvlei: Predicted increase in ambient atmospheric temperature (°C) for RCP 4.5 and 8.5 under mid- and far-future scenarios

TAve	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	1.7	1.4	1.3	1.6	1.1	1.7	1.5	1.3	1.4	1.4	1.2	1.8
RCP 4.5 Far	2.0	1.7	1.5	1.9	1.3	1.7	2.1	2.2	2.3	2.2	1.6	2.5
RCP 8.5 Mid	1.8	1.6	1.4	2.0	1.5	2.3	2.1	1.7	1.9	2.2	2.1	2.2
RCP 8.5 Far	3.9	3.4	3.6	3.5	4.0	4.1	3.8	3.3	3.6	3.8	3.7	3.7
Tmax	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	1.5	1.1	1.0	1.9	1.0	1.9	1.4	1.1	1.3	1.2	1.1	1.8
RCP 4.5 Far	1.6	1.3	1.0	2.1	1.2	1.8	2.4	2.0	2.5	2.1	1.6	2.5
RCP 8.5 Mid	1.3	1.3	1.0	1.9	1.3	2.5	2.1	1.7	1.9	2.2	2.0	1.9
RCP 8.5 Far	3.4	3.2	3.0	3.3	3.5	4.1	3.9	3.0	3.5	3.7	3.7	3.4
Tmin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	1.9	1.7	1.6	1.4	1.3	1.6	1.6	1.5	1.5	1.6	1.2	1.8
RCP 4.5 Far	2.4	2.1	2.0	1.7	1.4	1.6	1.9	2.3	2.0	2.3	1.5	2.5
RCP 8.5 Mid	2.3	1.9	1.7	2.1	1.7	2.2	2.2	1.8	1.9	2.2	2.2	2.4
RCP 8.5 Far	4.4	3.7	4.2	3.7	4.5	4.2	3.7	3.6	3.8	3.8	3.7	4.0

Table F.4: Swartvlei: Summary of broad measures of hydrological change (as reported in Cullis et al. 2015)

PARAMETER	PERCENTAGE CHANGE
Median Flows	-10%
Q 1 (Low flows)	-12 to -15%
Q 3 (Floods)	-5%
Min	-20%
Max	-0

Table F.5 provides a summary of potential change in runoff under RCP 4.5 and 8.5 scenarios for mid and far future conditions.

Table F.5: Swartvlei: Summary of potential change in runoff under RCP 4.5 and 8.5 scenarios for mid and far future conditions

SCENARIO NAME	DESCRIPTION	MAR (x 10^6 m^3)	PERCENTAGE REMAINING
Natural	Reference condition	83.2	
Present	Present	**56.6**	**68**
Scenario 1	RCP 4.5 Mid	**57.2**	**69**
Scenario 2	RCP 4.5 Far	**55.3**	**67**
Scenario 3	RCP 8.5 Mid	**54.8**	**66**
Scenario 4	RCP 8.5 Far	**51.7**	**62**

F.2 Abiotic Responses

F.2.1 Abiotic states and key characteristics

The characteristic abiotic states (and associated distinctive temporal patterns) for the Swartvlei are illustrated conceptually in Figure F.1.

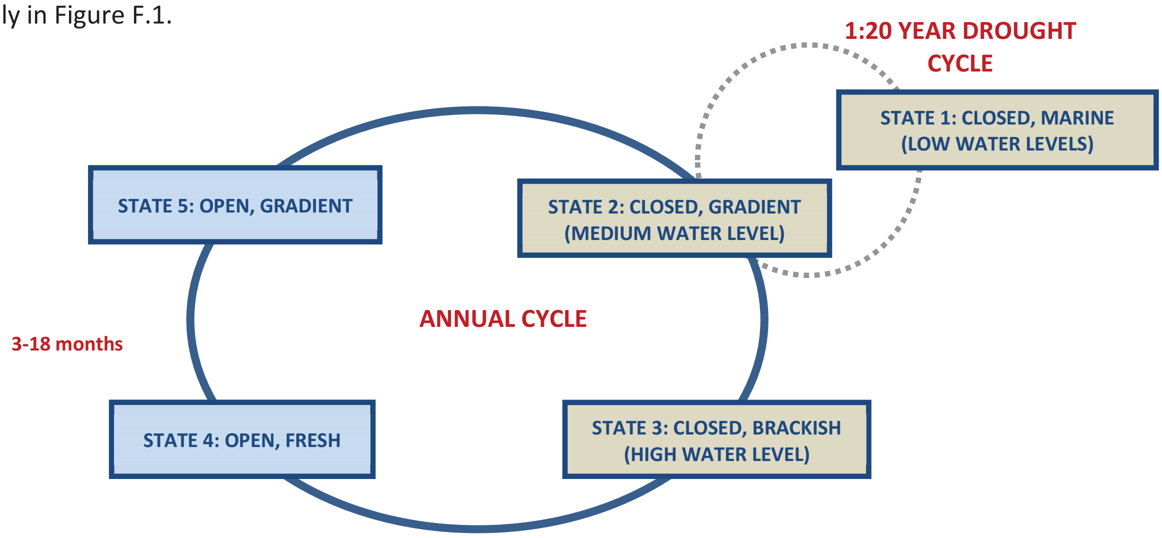


Figure F.1 Swartvlei: Distinctive temporal patterns in the distribution of abiotic states (present)

The mouth of Swartvlei is sensitive to high wave conditions (coupled with a reduction in runoff) and it shows a tendency to close during the winter when high waves tend to occur more frequently (Fijen 1995). Swartvlei is also sensitive to the neap-spring-neap tidal cycle as more closures occur on or after a neap tide in comparison to a spring tide. At present, the estuary mouth is artificially breached at about 2.0 m MSL. In the recent past, the system was even breached between 1.5 and 1.8 m MSL. The Swartvlei System natural breached at levels up to 3.5 m MSL (Fijen 1995). There is a relationship between the height of the berm and periods between breachings, i.e. the longer the system was closed the higher the berm. Mouth closure occurs between 0.5 m MSL and 1.0 m MSL. In general, the higher the water level in an estuary before a breaching event, the more efficient the scouring of sediment in the estuarine channels and mouth area during a breaching, resulting in longer periods of open mouth conditions after the breaching. This relationship is especially important in the case of the estuarine lakes as a small increase in breaching level results in significantly more outflow at breaching, i.e. a significant increase in scouring potential. Swartvlei mouth will close on average within about 2 months at a breaching level of ~1.5 m MSL and remain open for up to 3 years at a breaching level of ~3.5 m MSL (DWA 2009).

The system may well have been able to maintain open mouth condition more than two years under low flow conditions. At present, baseflows play an important role in maintaining open mouth conditions in the absence of effective scouring (DWA 2009). During droughts, the estuary can remain closed for longer than a year.

Five abiotic states have been identified in the Swartvlei Estuary (Table F.6), with *State 1: Closed, marine (very low water level)* associated with drought conditions as reflected in lake water levels below 0 m MSL. The lower estuary (Zone A) will be about 30, while the lake (Zone B) will be more than 15 (assuming > 1 year of closed conditions). During *State 2: Closed, gradient (medium water level)* water levels are between 0.8 and 1.5 m MSL. Salinity in the lower estuary (Zone A) is between 15 and 20, while the lake (Zone B) is highly stratified with surface water between 0 and 5, and bottom waters about 15. In *State 3: Closed, brackish (high water level)* levels are between 1.5 and 2.0 m MSL. Salinity in the lower estuary (Zone A) is about 10, while the lake (Zone B) is between 10 and 15 (assuming > 1 year of closed conditions). *State 4: Open, fresh* represents an open mouth state, with the lower estuary under tidal conditions. Lake levels are between 1.3 and 1.5 m. Salinity in the lower estuary (Zone A) is about 1, while the lake (Zone B) is highly stratified with surface water about 1, and bottom waters about 15. While in *State 5: Open*, gradient the system is subjected to tidal action and lower river inflow, resulting in salinity in the tidal lower estuary (Zone A) between 20 and 25, while the lake (Zone B) is highly stratified with surface water about 5, and bottom waters about 15. Lake levels are between 0.8 and 1.3.

Table F.6: Swartvlei: Key abiotic characteristics associated with various states

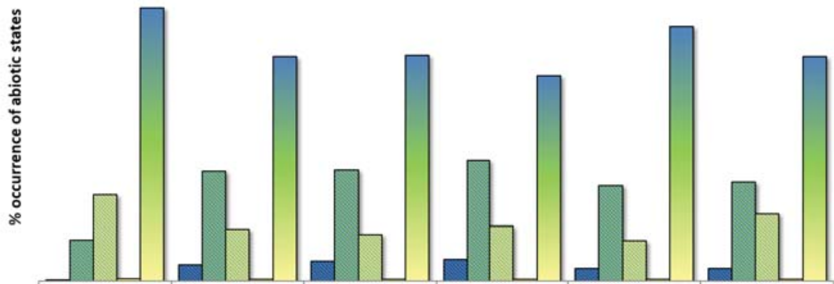
<table>
<tr><th>STATE</th><th>VARIABLE</th><th>A: LOWER ESTUARY</th><th>B: BASIN</th></tr>
<tr><td rowspan="4">State 1: Closed, marine (low water level)</td><td>WL:</td><td><0.5</td><td><0</td></tr>
<tr><td>Salinity:</td><td>30</td><td>>15 (> 1 year)</td></tr>
<tr><td>Temp:</td><td colspan="2">Summer: 25-29°C; Winter: 10-14°C</td></tr>
<tr><td>WQ:</td><td>NN (2)</td><td>MM</td></tr>
<tr><td rowspan="5">State 2: Closed, gradient (medium water level)</td><td>WL:</td><td colspan="2">0.8-1.5</td></tr>
<tr><td rowspan="2">Salinity:</td><td rowspan="2">15-20</td><td>0-5</td></tr>
<tr><td>15</td></tr>
<tr><td>Temp:</td><td colspan="2">Summer: 25-29°C; Winter: 10-14°C</td></tr>
<tr><td>WQ:</td><td>NN (2)</td><td>NN (2)
Naturally high DIN and low DO in deep bottom layers (remineralisation)</td></tr>
<tr><td rowspan="4">State 3: Closed, brackish (high water level)</td><td>WL:</td><td colspan="2">1.5-2.0 m</td></tr>
<tr><td>Salinity:</td><td>10</td><td>10-15 (> 1 year)</td></tr>
<tr><td>Temp:</td><td colspan="2">Summer: 25-29°C; Winter: 10-14°C</td></tr>
<tr><td>WQ:</td><td>NN (2)</td><td>MM</td></tr>
<tr><td rowspan="5">State 4: Open, fresh</td><td>WL:</td><td>0.5-1.3</td><td>1.3-3.5</td></tr>
<tr><td rowspan="2">Salinity:</td><td rowspan="2">1</td><td>1</td></tr>
<tr><td>15</td></tr>
<tr><td>Temp:</td><td colspan="2">Summer: 25-29°C; Winter: 10-14°C</td></tr>
<tr><td>WQ:</td><td>NN (2)</td><td>NN (2)
Naturally high DIN and low DO in deep bottom layers (remineralisation)</td></tr>
<tr><td rowspan="5">State 5: Open, gradient</td><td>WL:</td><td>0-1.3</td><td>0.8-1.3</td></tr>
<tr><td rowspan="2">Salinity:</td><td rowspan="2">20-25</td><td>5</td></tr>
<tr><td>15</td></tr>
<tr><td>Temp:</td><td colspan="2">Summer: 25-29°C (lower temperature can occur in lower estuary during upwelling); Winter: 10-14°C</td></tr>
<tr><td>WQ:</td><td>NN(2)</td><td>NN
Naturally high DIN and low DO in deep bottom layers (remineralisation)</td></tr>
</table>

In the lower estuary (Zone A), inorganic nutrient (DIN) concentrations are generally low. During upwelling (known to occur along this coast particularly during summer) nutrient concentrations near the mouth can increase, but this would also have been the case under reference conditions. It can be expected for nutrient concentrations in the estuary to be higher during high flow, associated with enriched runoff from the catchment. During high flows, it can be expected for inorganic nutrient concentration in the lower estuary to increase slightly associated with enriched runoff from the catchment. The relative shallow lower estuary is generally well-oxygenated throughout (DWAF 2009).

Nutrient concentrations (DIN) in surface waters in the basin (Zone B) are generally low. When the basin becomes well-mixed nutrient concentrations can be expected to be relatively low. However, when the basin stratifies nutrient concentrations in the deep bottom layers can be high (specifically NH_4-N), associated with remineralisation of organic matter. In the littoral zone high sediment nutrients are accessible to rooted plants but this area acts as an efficient nutrient sink, without any significant 'loss' of nutrients to the larger water column. During high flow nutrients in the surface waters of the basin can be slightly higher, associated with enriched catchment runoff. When the basin becomes stratified DO concentrations show strong vertical stratification (~5 m water depth), where oxic conditions exist in the surface layers and anoxic conditions in the deep bottom waters. When the basin becomes well mixed, the bottom layer is gradually replenished with oxygen as older bottom waters get eroded (DWAF 2009).

F.2.2 Responses to climate change scenarios

The Swartvlei Estuary responds to river flow in all its variability. Breaching is dependent on the total inflow, while the duration of the open period responds to the breaching level, mouth position and occurrence of higher flow event post-breaching. Predicted changes in hydrodynamic functioning, average water level, salinity and marine connectivity are captured in the overall occurrence of different abiotic states in the Swartvlei estuary are summarised in Figure F.2. Notable is the decrease in State1: Closed Marine and State 2: Closed gradient from present under RCP 8.5, with a shift towards State 5: Open gradient conditions under Scenario 3, and Sate 3: Closed Brackish under Scenario 5.



	Natural	Present	Sc1: RCP 4.5 Mid	Sc 2: RCP 4.5 Far	Sc 3: RCP 8.5 Mid	Sc 4: RCP 8.5 Far
State 1: Closed Marine (LW level)	0.3	4.0	5.0	5.4	3.1	3.2
State 2: Closed gradient (MW level)	10.1	27.1	27.4	29.8	23.5	24.4
State 3: Closed Brackish (HW level)	21.3	12.8	11.4	13.6	10.0	16.5
State 4: Open Fresh	0.6	0.5	0.4	0.5	0.4	0.4
State 5: Open gradient	67.7	55.7	55.9	50.8	63.0	55.6

Figure F.2: Swartvlei: Occurrence of abiotic states under different scenarios

Mouth conditions showed limited sensitivity to the changes in river flow to the estuary. Under Scenario 1 and 4, mouth conditions are like the present regime, while under Scenario 2 the mouth of the estuary will be about 5% less open than under the current conditions. Scenario 3 shows an increase in open mouth conditions from the present, thus moving towards natural conditions (Figure F.3 and Table F.7).

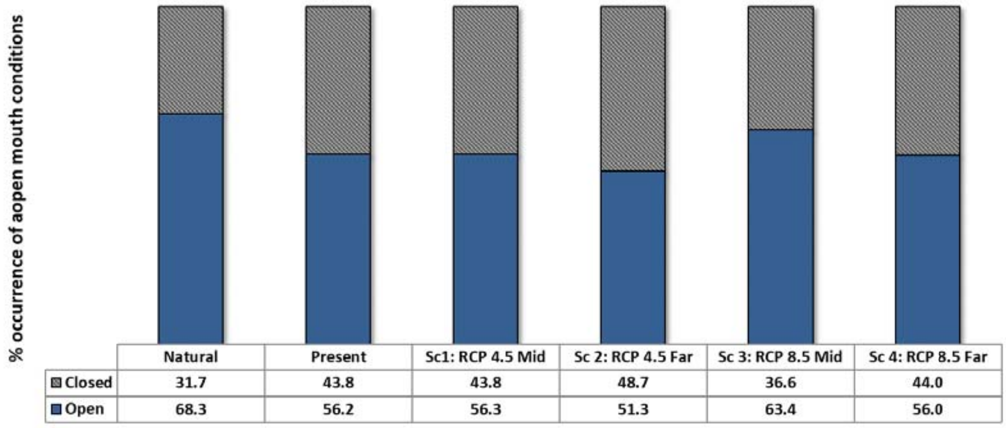


Figure F.3: Swartvlei: Overall occurrence of open mouth conditions (expressed as % open) under different scenarios

Table F.7: Swartvlei: Estimated percentage time the Swartvlei estuarine lake is connected to the sea under different scenarios (darker colours indicate high connectivity and light colours low connectivity)

	PRESENT		SWARTVLEI: SC 1		SWARTVLEI: SC 2		SWARTVLEI: SC 3		SWARTVLEI:SC4	
	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B
SEASONAL DISTRIBUTION (84 YEAR SIMULATION PERIOD)										
January	74	74	76	76	67	67	79	79	74	74
February	77	77	79	79	70	70	81	81	75	75
March	80	80	85	85	81	81	88	88	82	82
April	82	82	85	85	81	81	89	89	85	85
May	83	83	94	94	92	92	89	89	87	87
June	6	6	2	2	4	4	23	23	10	10
July	14	14	10	10	7	7	27	27	18	18
August	25	25	23	23	19	19	35	35	29	29
September	39	39	38	38	32	32	46	46	40	40
October	56	56	55	55	45	45	60	60	50	50
November	67	67	62	62	56	56	70	70	56	56
December	70	70	68	68	62	62	74	74	67	67

(Note: consistent mouth closures in June are an artefact of the water balance model forcing the system close in winter to reflect the impact of increased storms along the coast in this season)

Artificial breaching has reduced the maximum water levels from 3.5 m MSL to about 2.0 m MSL, thus representing a huge anthropogenic induced shift in conditions. Comparing water levels under the future climate conditions shows that average water levels decrease only slightly (5-10 cm) under the future Scenario 1 and 3, and only increase slightly under Scenarios 2 to 4 (5-10 cm). Scenario 1 to 3 shows some seasonal declines in water levels during summer. A broad summary is provided below in Table F.8.

Table F.8: Swartvlei: Predicted water level (m) under Present and Future Climate Change Scenarios

	PRESENT		SWARTVLEI: SC 1		SWARTVLEI: SC 2		SWARTVLEI: SC 3		SWARTVLEI:SC4	
	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B
SEASONAL DISTRIBUTION (84 YEAR SIMULATION PERIOD)										
January	0.9	1.1	0.8	1.0	0.9	1.1	0.8	1.1	0.9	1.1
February	0.8	1.1	0.8	1.1	0.9	1.1	0.8	1.1	0.9	1.1
March	0.8	1.1	0.8	1.0	0.8	1.1	0.8	1.0	0.8	1.1
April	0.8	1.1	0.8	1.1	0.9	1.1	0.8	1.0	0.8	1.1
May	0.8	1.1	0.7	1.0	0.7	1.1	0.8	1.1	0.8	1.1
June	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.2	1.2
July	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.2	1.2
August	1.2	1.2	1.1	1.2	1.2	1.2	1.1	1.2	1.2	1.3
September	1.1	1.2	1.1	1.2	1.1	1.2	1.1	1.2	1.1	1.2
October	1.0	1.2	1.0	1.2	1.1	1.2	1.0	1.1	1.1	1.2
November	0.9	1.1	1.0	1.2	1.0	1.1	0.9	1.1	1.0	1.2
December	0.9	1.1	0.9	1.1	1.0	1.1	0.9	1.1	1.0	1.2
PERCENTILE DISTRIBUTION (84 YEAR SIMULATION PERIOD)										
99%ile	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
95%ile	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
90%ile	1.8	1.8	1.8	1.8	1.8	1.8	1.4	1.8	1.8	1.8
80%ile	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
70%ile	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
60%ile	0.7	1.2	0.7	1.0	1.2	1.2	0.7	1.0	1.2	1.2
50%ile (median)	0.7	1.0	0.7	1.0	0.7	1.0	0.7	1.0	0.7	1.0
40%ile	0.7	1.0	0.7	1.0	0.7	1.0	0.7	1.0	0.7	1.0
30%ile	0.7	1.0	0.7	1.0	0.7	1.0	0.7	1.0	0.7	1.0
20%ile	0.7	1.0	0.7	1.0	0.7	1.0	0.7	1.0	0.7	1.0
10%ile	0.7	1.0	0.7	1.0	0.7	1.0	0.7	1.0	0.7	1.0
1%ile	0.5	0.0	0.5	0.0	0.5	0.0	0.5	0.0	0.5	0.0

As a result of the estuary mouth now remaining open for shorter periods than under natural the system is now fresher than under the natural conditions. Comparing salinity regimes under the future climate conditions Scenario 1 to 4 are very similar to the present. There is a slight decrease in salinity under Scenario 2 and a slight increase under Scenario 4. A summary of the result is presented in Table F.9.

Table F.9: Swartvlei: Predicted salinity under Present State and Future Climate Change Scenarios

	PRESENT		SWARTVLEI: SC 1		SWARTVLEI: SC 2		SWARTVLEI: SC 3		SWARTVLEI:SC4	
	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B
SEASONAL DISTRIBUTION (84 YEAR SIMULATION PERIOD)										
January	23	10	23	10	22	10	23	10	23	10
February	23	10	23	10	22	10	23	10	23	10
March	23	9	24	10	23	10	24	10	23	9
April	23	10	24	10	23	10	24	10	23	10
May	23	10	24	10	24	10	24	10	23	10
June	20	7	22	7	21	7	21	7	20	8
July	20	7	20	7	21	7	21	8	19	8
August	20	8	20	7	19	7	20	8	19	8
September	20	8	21	8	20	8	21	8	20	9
October	21	9	21	9	20	9	22	9	20	9
November	22	9	21	9	21	9	23	9	21	9
December	22	9	22	9	22	9	23	9	22	9
PERCENTILE DISTRIBUTION (84 YEAR SIMULATION PERIOD)										
99%ile	30	15	30	15	30	15	30	15	30	15
95%ile	25	10	25	10	30	15	25	10	25	10
90%ile	25	10	25	10	25	10	25	10	25	10
80%ile	25	10	25	10	25	10	25	10	25	10
70%ile	25	10	25	10	25	10	25	10	25	10
60%ile	25	10	25	10	25	10	25	10	25	10
50%ile (median)	25	10	25	10	25	10	25	10	25	10
40%ile	20	10	25	10	20	10	25	10	20	10
30%ile	20	10	20	10	20	5	20	10	20	10
20%ile	20	5	20	5	20	5	20	5	20	5
10%ile	10	5	10	5	10	5	10	5	10	5
1%ile	10	5	10	5	10	5	10	5	10	5

Predicted changes in seasonal and percentile distribution of water quality under present and future Climate Change scenarios are provided in Table F.10. Present water quality in the Swartvlei system is mostly still in a near-natural state, except during some closed and well-mixed states (e.g. State 1) when nutrients in Zone B show a slight increase at times because nutrients accumulated in bottom waters are mixed into the entire water column. However, it is not expected for any of the future Climate Change scenarios to cause marked shifts in water quality from the present.

Table F.10: Swartvlei: Predicted water quality under Present State and Future Climate Change Scenarios

	SWARTVLEI: PRESENT		SWARTVLEI: SCENARIO 1		SWARTVLEI: SCENARIO 2		SWARTVLEI: SCENARIO 3		SWARTVLEI: SCENARIO 4	
	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B
SEASONAL DISTRIBUTION (SIMULATION PERIOD)										
January	2	2	2	2	2	2	2	2	2	2
February	2	2	2	2	2	2	2	2	2	2
March	2	2	2	2	2	2	2	2	2	2
April	2	2	2	2	2	2	2	2	2	2
May	2	2	2	2	2	2	2	2	2	2
June	2	2	2	2	2	2	2	2	2	2
July	2	2	2	2	2	2	2	2	2	2
August	2	2	2	2	2	2	2	2	2	2
September	2	2	2	2	2	2	2	2	2	2
October	2	2	2	2	2	2	2	2	2	2
November	2	2	2	2	2	2	2	2	2	2
December	2	2	2	2	2	2	2	2	2	2
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)										
95%ile	2	3	2	3	2	3	2	3	2	3
90%ile	2	3	2	3	2	3	2	3	2	3
80%ile	2	2	2	2	2	2	2	2	2	2
70%ile	2	2	2	2	2	2	2	2	2	2
60%ile	2	2	2	2	2	2	2	2	2	2
50%ile (median)	2	2	2	2	2	2	2	2	2	2
40%ile	2	2	2	2	2	2	2	2	2	2
30%ile	2	2	2	2	2	2	2	2	2	2
20%ile	2	2	2	2	2	2	2	2	2	2
10%ile	2	2	2	2	2	2	2	2	2	2

F.3 Biotic Responses

F.3.1 Microalgae

The conceptual model for microalgal characteristics under different abiotic scenarios is illustrated in Figure F.4, while the microalgal characteristics associated with different zone are summarised in Table 14.11. Phytoplankton biomass is generally low in Swartvlei (~Good: < 5 µg/ℓ) due to the reduced freshwater inflow and prolonged periods of mouth closure (State 1-3) that facilitate macrophyte growth (DWA, 2009). Additionally, flood events (~State 4) typically scour the system and dilute microalgal biomass (phytoplankton and benthic microalgae – 'Good' condition). However, once freshwater inflow reduces (~State 5), phytoplankton biomass has been shown to accumulate (~Poor: ≥ 20 but < 60 µg/ℓ) in conjunction with brackish and stratified conditions in the lower estuary (Zone A) and basin (Zone B~ near tributaries).

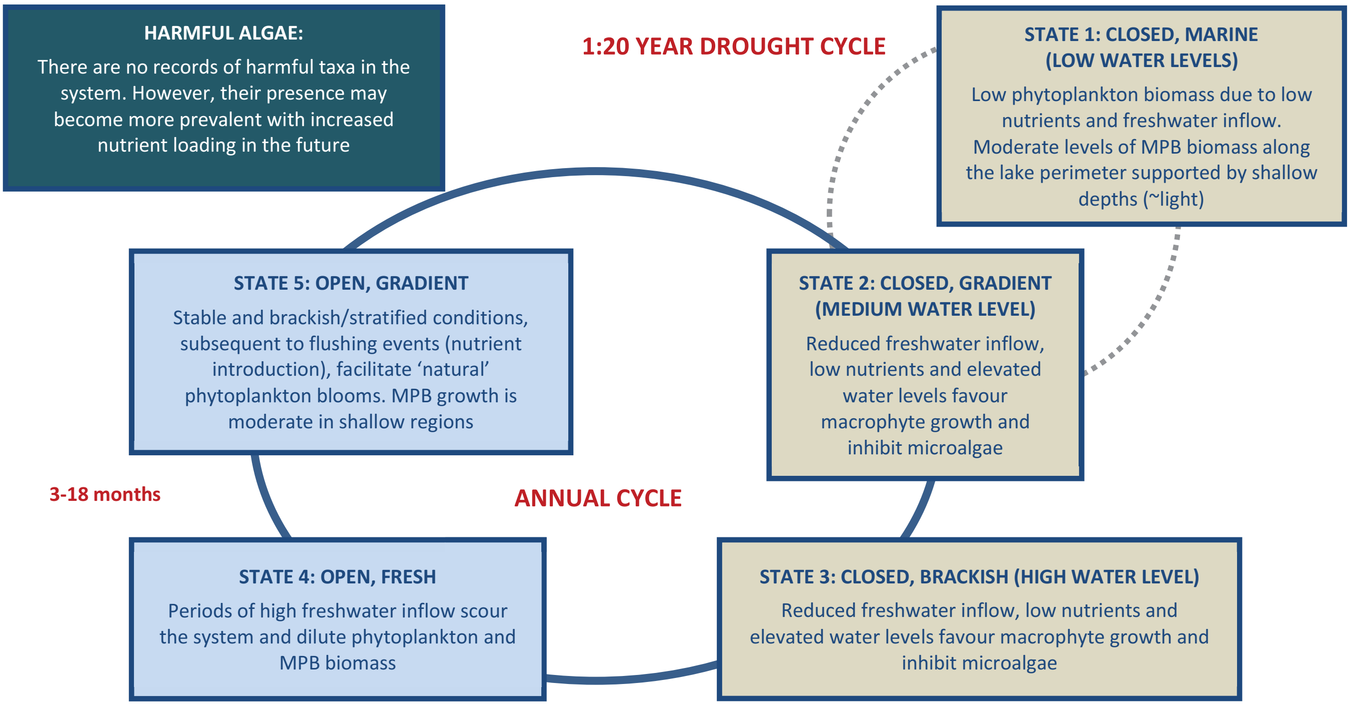


Figure F.4: Swartvlei: Microalgae Conceptual model

Given the stratified nature of the system during this state, it is likely that dinoflagellates are responsible for such bloom events. As river flow becomes negligible (State 1-3), small-celled taxa belonging to Cryptophyceae, Chlorodendrophyceae and Cyanophyceae (cyanobacteria) most likely comprise the phytoplankton community during brackish and nutrient-replete conditions.

Table F.11: Swartvlei: Key microalgal characteristics associated with various states

STATE	PARAMETER	ZONE A: LOWER ESTUARY	ZONE B: BASIN
State 1: Closed, marine (low water level)	Phytoplankton:		
	Benthic microalgae:		
	Harmful algae:		
State 2: Closed, gradient (medium water level)	Phytoplankton:		
	Benthic microalgae:		
	Harmful algae:		
State 3: Closed, brackish (high water level)	Phytoplankton:		
	Benthic microalgae:		
	Harmful algae:		
State 4: Open, fresh	Phytoplankton:		
	Benthic microalgae:		
	Harmful algae:		
State 5: Open, gradient	Phytoplankton:		
	Benthic microalgae:		
	Harmful algae:		

Confidence levels: Phytoplankton – Medium; Benthic microalgae – Low; Harmful algae – Low

Despite a lack of information, benthic microalgal biomass is expected to be low (~Good: < 50 mg/m^2) throughout the system due to low nutrient availability, coarse sediments and increased water level (~reduced light penetration) (State 2-4). Slight increases in benthic microalgal biomass are expected (~Fair: ≥ 50 but < 100 mg/m^2) along the perimeter of the lake systems during low water level periods (State 1 and 5). There are no available data regarding the presence of harmful algal species in Swartvlei. The blooms documented to occur during State 5 (open, gradient) are likely to be a natural process in which newly introduced nutrients support episodic phytoplankton productivity; however, further anthropogenic manipulation (e.g. nutrient loading) of the system into the future, coupled with climate change (e.g. warmer, more floods), may lead to increased harmful algal bloom instances.

A summary of the key responses in microalgae under the Present State and Future Climate Change scenarios are summarized in Table B.12. Predicted changes in seasonal and percentile distribution of microalgae under present and future Climate Change scenarios are provided in Tables B.13 to B.15.

Table F.12: Swartvlei: Predicted change in microalgae under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Microalgal biomass is generally low due to the reduced freshwater inflow and prolonged periods of mouth closure – compared to natural – that facilitates macrophyte growth. Phytoplankton peaks are observed after flood events that initially introduce nutrients and cause a shift towards brackish/stratified conditions. However, this is a natural cycle and HAB species have not been reported.
1	A slight reduction in water levels (5-10 cm) facilitates a slight increase in MPB biomass, while phytoplankton/HAB scores remain the same as present.
2	Decreased salinity, more frequent periods of mouth closure and increased water levels (5-10 cm) favour emergent macrophyte growth and hinders phytoplankton biomass.
3	A predicted shift towards increased open mouth conditions favours the growth of phytoplankton (i.e. stratification) and benthic microalgae (i.e. reduced water levels), particularly during the warm summer period.
4	An increase in water levels and salinity, together with marked increases in temperature, are expected to increase the likelihood of phytoplankton blooms and the presence of HAB species. Additionally, benthic microalgae are expected to increase in the shallower lower reaches during warmer conditions.

Table F.13: Swartvlei: Predicted Phytoplankton under Present State and Future Climate Change Scenarios

	SWARTVLEI: PRESENT		SWARTVLEI: SCENARIO 1		SWARTVLEI: SCENARIO 2		SWARTVLEI: SCENARIO 3		SWARTVLEI: SCENARIO 4	
	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B
SEASONAL DISTRIBUTION (SIMULATION PERIOD)										
January	3	3	3	3	3	2	3	3	3	3
February	3	3	3	3	3	3	4	3	4	3
March	3	3	4	3	3	3	4	3	4	3
April	4	3	4	3	4	3	4	3	4	3
May	4	3	4	3	4	3	4	3	4	3
June	1	1	1	1	1	1	2	2	2	2
July	2	1	1	1	1	1	2	2	2	2
August	2	2	2	2	2	2	2	2	3	2
September	2	2	2	2	2	2	3	2	3	2
October	3	2	3	2	3	2	3	2	3	3
November	3	2	3	2	3	2	3	3	3	3
December	3	3	3	2	3	2	3	3	3	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)										
95%ile	4	3	4	3	4	3	4	3	4	3
90%ile	4	3	4	3	4	3	4	3	4	3
80%ile	4	3	4	3	4	3	4	3	4	3
70%ile	4	3	4	3	4	3	4	3	4	3
60%ile	4	3	4	3	4	3	4	3	4	3
50%ile (median)	4	3	4	3	4	3	4	3	4	3
40%ile	2	2	2	2	2	2	4	3	2	2
30%ile	1	1	1	1	1	1	2	2	2	2
20%ile	1	1	1	1	1	1	1	1	2	2
10%ile	1	1	1	1	1	1	1	1	2	2

Table F.14: Swartvlei: Predicted Benthic microalgae under Present State and Future Climate Change Scenarios

	SWARTVLEI: PRESENT		SWARTVLEI: SCENARIO 1		SWARTVLEI: SCENARIO 2		SWARTVLEI: SCENARIO 3		SWARTVLEI: SCENARIO 4	
	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B
SEASONAL DISTRIBUTION (SIMULATION PERIOD)										
January	1	3	1	3	1	2	1	3	2	3
February	1	3	1	3	1	3	1	3	2	3
March	1	3	1	3	1	3	1	3	2	3
April	1	3	1	3	1	3	1	3	2	3
May	1	3	1	3	1	3	1	3	2	3
June	1	1	1	1	1	1	1	2	2	2
July	1	1	1	1	1	1	1	2	2	2
August	1	2	1	2	1	1	1	2	2	2
September	1	2	1	2	1	2	1	2	2	2
October	1	2	1	2	1	2	1	2	2	2
November	1	2	1	2	1	2	1	2	2	2
December	1	2	1	2	1	2	1	3	2	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)										
95%ile	1	3	1	3	3	3	1	3	2	3
90%ile	1	3	1	3	1	3	1	3	2	3
80%ile	1	3	1	3	1	3	1	3	2	3
70%ile	1	3	1	3	1	3	1	3	2	3
60%ile	1	3	1	3	1	3	1	3	2	3
50%ile (median)	1	3	1	3	1	3	1	3	2	3
40%ile	1	1	1	3	1	1	1	3	2	2
30%ile	1	1	1	1	1	1	1	1	2	2
20%ile	1	1	1	1	1	1	1	1	2	2
10%ile	1	1	1	1	1	1	1	1	1	1

Table F.15: Predicted Harmful algae under Present State and Future Climate Change Scenarios

	SWARTVLEI: PRESENT		SWARTVLEI: SCENARIO 1		SWARTVLEI: SCENARIO 2		SWARTVLEI: SCENARIO 3		SWARTVLEI: SCENARIO 4	
	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B	Zone A	Zone B
SEASONAL DISTRIBUTION (SIMULATION PERIOD)										
January	2	2	3	2	2	2	3	2	3	3
February	3	2	3	2	2	2	3	2	3	3
March	3	2	3	2	3	2	3	2	3	3
April	3	2	3	2	3	2	3	2	3	3
May	3	2	3	2	3	2	3	2	3	3
June	1	1	1	1	1	1	1	1	2	2
July	1	1	1	1	1	1	2	1	2	2
August	1	1	1	1	1	1	2	1	2	2
September	2	1	2	1	2	1	2	1	2	2
October	2	2	2	2	2	1	2	2	3	3
November	2	2	2	2	2	2	2	2	3	3
December	2	2	2	2	2	2	2	2	3	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)										
95%ile	3	2	3	2	3	2	3	2	3	3
90%ile	3	2	3	2	3	2	3	2	3	3
80%ile	3	2	3	2	3	2	3	2	3	3
70%ile	3	2	3	2	3	2	3	2	3	3
60%ile	3	2	3	2	3	2	3	2	3	3
50%ile (median)	3	2	3	2	3	2	3	2	3	3
40%ile	1	1	1	1	1	1	3	2	2	2
30%ile	1	1	1	1	1	1	1	1	2	2
20%ile	1	1	1	1	1	1	1	1	2	2
10%ile	1	1	1	1	1	1	1	1	2	2

F.3.2 Macrophytes

Submerged macrophytes and reeds are the largest macrophyte habitat present. Both *Zostera capensis* and *Ruppia cirrhosa* occur depending on the salinity, as does *Stuckenia pectinata.* The Charophytes *Chara globularis* var *kraussii* and *Lamprothamnium papulosum* occur at depths less than 1 m (DWS 2019). Reduced water transparency often associated with floods reduces their abundance. Salinity above 15 removes *Stuckenia pectinata* and the Charophytes (Howard-Williams and Liptrot 1980).

Reeds and sedge habitat is mainly *Phragmites australis* and *Schoenoplectus scirpoideus* and is limited to 2 m depth. During extended open and marine states saline water results in the die back of reeds and freshwater submerged vegetation. The macroalga *Ulva instestinalis* was reported to form dense mats in the estuary as does the epiphytic green alga *Enteromorpha* which can form dense algal mats over the *Zostera* beds in the winter.

An increase in nutrients coupled with prolonged mouth closure would increase the abundance of macroalgae. The marginal salt marshes of the estuary are flooded during high spring tide and when the mouth is closed and include *Sarcocornia natalensis*, *Salicornia meyeriana*, *Paspalum vaginatum*, *Sporobolus virginicus* and *Juncus kraussii*. (DWS 2019). The macrophyte conceptual model for Swartvlei is presented in Figure F.5.

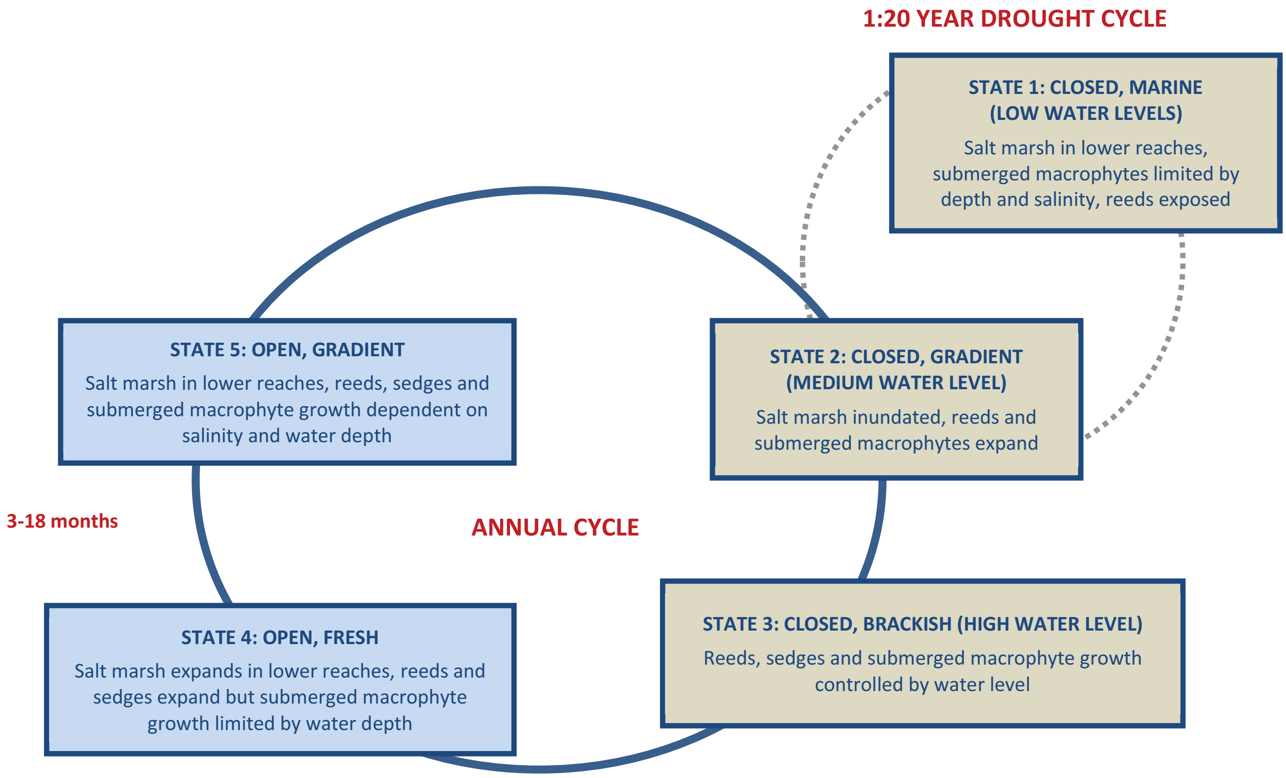


Figure F.5 Swartvlei: Macrophyte Conceptual model

Salt marsh in the lower estuarine section, mouth open and water level low (27 Jan 2019).

Closed, water level high – salt marsh in lower reaches flooded (9 May 2006).

Open, low (left) – reeds and submerged exposed (15 May 2003) compared to closed and full (right) (9 May 2006)

Responses of Macrophytes to different scenarios are illustrated in Table F.16.

Table F.16: Swartvlei: Predicted change in macrophytes under future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Salt marsh (91.4 ha), Submerged macrophytes (219.4 ha), Reeds and sedges (167.06 ha). From reference to present state there has been an increase in the closed mouth state. Development has removed 5% of the reed and sedge habitat in Zone B and 10% of the salt marsh habitat. Other losses of macrophyte habitat can be related to disturbance by boats and loss of intertidal areas due to extended mouth closure. Overall changes: 5% (Zone B reeds and sedges) + 15% (Zone A salt marsh) + 5% (Zone A estuary submerged macrophytes).
1	Conditions are very similar to present and macrophyte scores remain the same.
2	As the system closes more often (49% of the time) and salinity decreases submerged macrophytes, reeds and sedges will increase. Salt marsh will decrease as the habitat is inundated.
3	Increase in mouth condition moving towards reference condition. There is a 2.3% decrease in MAR. Water level drops between 5 to 10 cm, with seasonal decline during summer, but salinity similar to present. There is an increase in the open mouth state (63% of the time) bringing the estuary closer to reference conditions. As water level drops reeds, sedges and submerged macrophytes will decrease in cover in Zone B closer to reference conditions. Salt marsh will increase in the lower reaches (Zone A) and the intertidal zone will expand likely resulting in a spread of the seagrass *Zostera capensis*.
4	As water level increases reeds and sedges will die back and submerged macrophytes will increase under the increase in closed brackish conditions. Salt marsh will decrease due to inundation of habitat. Higher temperatures will encourage macroalgal growth as well as the fresher conditions in Zone B.

F.3.3 Fish

At least 33 fish species are known to occur in Swartvlei and 58 species in the lower estuary (DWA 2009). Many of these taxa are either totally or partially dependent on the estuarine environment and a high proportion of the species found within the system are endemic to southern Africa. The rare and endangered Knysna seahorse (*Hippocampus capensis*), which is confined to three estuaries in the southern Cape, is found within aquatic macrophyte beds of the lower estuary. The large number of juvenile marine fish that occur in the littoral zone of both the lake and lower estuary reflects the importance of this large system to many coastal species. The Fish conceptual model for Swartvlei is presented in Figure F.6.

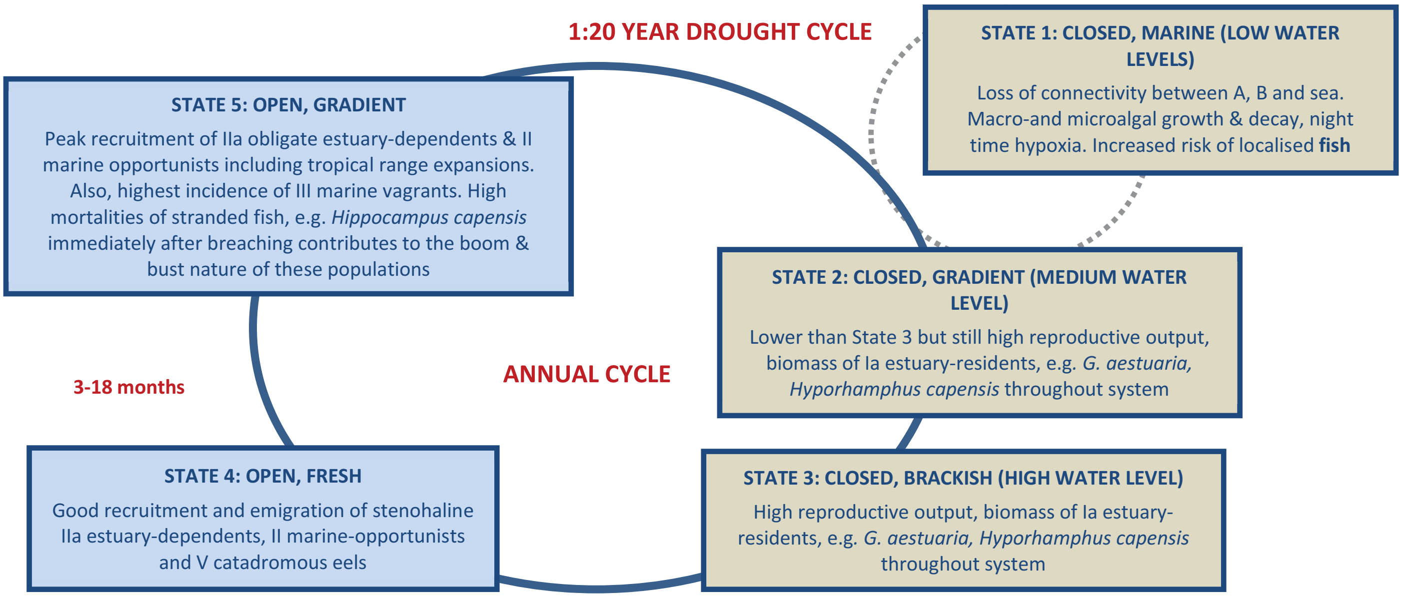


Figure F.6: Swartvlei: Fish Conceptual model

Predicted change in fish under present and various climate change scenarios is provided in Table F.17.

Table F.17: Swartvlei: Predicted change in fish under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Species Richness: Lake: Introduction of the mosquito fish Gambusia affinis, banded tilapia *sparrmanii* and Mozambique tilapia *Oreochromis mossambicus* to Swartvlei will have resulted in small changes in fish species richness when compared to the Reference Condition. Estuary: The more continuous open and closed mouth conditions in the Reference Condition would have resulted in a species richness that would have deviated slightly from the Present State. Abundance: Lake: Loss of small areas of submerged aquatic macrophytes due to jetties and boating activities would have resulted in a slight decrease in macrophyte associated fish species abundance when compared to the Reference Condition. Widespread loss of submerged macrophytes (as occurred in the 1980s) would have a major impact on fish abundance in Swartvlei. Sustained recreational angling in the Present State would also have had a negative impact on the abundance of predatory fish species within the lake. Estuary: Encroaching development and reclamation of wetland areas would have reduced the food production and available habitat for fishes. This, together with a possible loss of submerged macrophytes due to boating and bait collecting activities, would have resulted in smaller fish populations. Localised decomposition of macroalgal mats is also likely to cause reduced fish abundance in the littoral zone but this type of event may also have occurred in the Reference Condition. Recreational and subsistence angling places additional pressures on the predatory fish species within the estuary. Community composition: Lake: If the temporary loss of submerged macrophytes is due to catchment degradation or other anthropogenic impacts, then the Present State fish community composition can sometimes differ considerably from the Reference Condition. Macrophyte senescence results in a decrease in fish species that are associated with these plants (e.g. Cape stumpnose) and an increase in fishes that are associated with bare sediments (e.g. mullet). Angling which targets predatory fish species would also have shifted the community composition when compared to the Reference Condition. Estuary: Any increase in nutrients which promotes the proliferation of macroalgae at the expense of aquatic macrophyte beds would alter the fish community composition in the estuary. When these macroalgal mats decompose, localised hypoxic conditions would develop and cause major changes in the associated fish assemblages. Angling which targets predatory fish species would also have shifted the community composition when compared to the Reference Condition.
1-3	Closed fresher high-water levels favour estuarine residents *G. aestuaria* and *A. breviceps* but also *Clinus spatulatus* which experiences population booms during closure, bust on opening. Submerged macrophytes increase during closure which also favours these species. Limited recruitment via over-wash but populations of marine opportunists and obligate estuary-dependent species comprise mostly one or two cohorts that recruited during the previous opening. Synchronised mouth opening events and genetic exchange between Swartvlei and Touw/Wilderness estuary-residents becomes more limited. Lower salinity after prolonged closure sees invasion of translocated *Oreochromis mossambicus* (or *O. niloticus* hybrid) and alien fish, e.g. *C. carpio* into the main water body from upstream. Fresh conditions throughout may see some stress and few mortalities in the less euryhaline species. Alternatively, hypersalinity resulting from drought and low-flow during closure may see fish kills from osmotic stress once salinity exceeds 45.
4	Endemic Ia fish find refuge in fresher Zone A. Marine opportunists (e.g. *C. richardsonii*) still throughout the system but stressed after salinity > 40, mortalities start after 45. Macrophyte replaced by macroalgal refuge. Benthic burrowing invertebrates nearer

G. uMGOBEZELENI

G.1 Predicted Climate Change Scenarios

Predicted climate change scenarios for RCP 4.5 and 8.5 under mid and far future scenarios relevant to the uMgobezeleni system, are presented in Tables G.1 to G.3 for precipitation in the catchment, precipitation in EFZ and ambient atmospheric temperature, respectively. A summary of broad measures of hydrological changes, as reported by Cullis et al. (2015), is provided in Table G.4.

Table G.1: uMgobezeleni: Predicted change in precipitation in catchment for RCP 4.5 and 8.5 under mid- and far-future scenarios

CATCHMENT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	-15	-10	18	-6	1	-21	4	-31	12	-10	-11	12
RCP 4.5 Far	-8	7	22	-22	2	-35	3	-11	-14	22	22	3
RCP 8.5 Mid	-3	-9	7	-27	16	-32	10	12	25	-14	2	-7
RCP 8.5 Far	9	15	27	-12	-22	-38	6	-32	-29	-32	19	28

Table G.2: uMgobezeleni: Predicted change in precipitation in EFZ for RCP 4.5 and 8.5 under mid- and far-future scenarios

ESTUARY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	-24	-10	21	-9	-2	-16	-5	-39	8	-11	-13	13
RCP 4.5 Far	-12	14	22	-25	4	-35	-6	-19	-16	16	18	10
RCP 8.5 Mid	-7	-4	3	-28	9	-30	-4	1	25	-18	-2	-6
RCP 8.5 Far	11	9	20	-12	-29	-40	-11	-42	-40	-35	16	27

Table G.3: uMgobezeleni: P predicted increase in ambient atmospheric temperature (°C) for RCP 4.5 and 8.5 under mid- and far-future scenarios

TAve	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	1.6	1.6	1.3	1.5	1.8	1.6	2.1	1.7	1.5	1.4	1.2	1.6
RCP 4.5 Far	2.0	1.9	1.9	2.0	1.9	1.7	2.4	2.0	2.4	2.2	1.4	2.0
RCP 8.5 Mid	1.8	1.9	1.9	2.3	2.1	2.2	2.5	1.7	2.1	2.1	1.7	2.0
RCP 8.5 Far	4.2	3.8	3.9	4.0	4.4	4.3	4.3	3.8	4.2	4.1	3.6	3.9
Tmax	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	1.6	1.6	1.4	1.5	1.6	1.6	1.8	1.6	1.5	1.2	1.2	1.5
RCP 4.5 Far	1.9	1.9	2.0	1.9	1.8	1.7	2.1	1.9	2.5	2.1	1.3	2.0
RCP 8.5 Mid	1.9	1.8	2.0	2.2	1.9	2.1	2.1	1.8	2.0	1.9	1.6	2.0
RCP 8.5 Far	4.2	3.7	3.9	3.9	4.0	3.9	3.8	3.5	4.0	3.9	3.6	3.9
Tmin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	1.6	1.7	1.2	1.5	2.0	1.7	2.4	1.8	1.4	1.6	1.3	1.6
RCP 4.5 Far	2.0	1.9	1.9	2.0	1.9	1.8	2.7	2.1	2.2	2.3	1.4	2.0
RCP 8.5 Mid	1.8	2.0	1.9	2.4	2.3	2.2	2.8	1.7	2.2	2.2	1.8	2.1
RCP 8.5 Far	4.3	3.9	4.0	4.1	4.9	4.7	4.8	4.1	4.4	4.2	3.7	4.0

Table G.4: Summary of broad measures of hydrological change as reported by Cullis et al 2015

	Percentage change
Median Flows	+5%
Q 1 (Low flows)	0 to -5%
Q 3 (Floods)	+10% to +15%
Min	-20%
Max	+30%

Table G.5 provides a summary of potential change in runoff under RCP 4.5 and 8.5 scenarios for mid and far future conditions.

Table G.5: uMgobezeleni: Summary of potential change in runoff under RCP 4.5 and 8.5 scenarios for mid and far future conditions

SCENARIO NAME	DESCRIPTION	PERCENTAGE SIMILARITY (trajectory of change)
Natural	Reference condition	
Present	Present	5-10% ↓ from natural
Scenario 1	RCP 4.5 Mid	2-5% ↓ from present
Scenario 2	RCP 4.5 Far	5-10% ↑ from present
Scenario 3	RCP 8.5 Mid	2-5% ↓ from present
Scenario 4	RCP 8.5 Far	5-10% ↑ from present

G.2 Abiotic Responses

G.2.1 Abiotic states and key characteristics

The characteristic abiotic states (and associated distinctive temporal patterns) for the uMgobezeleni are illustrated conceptually in Figure G.1.

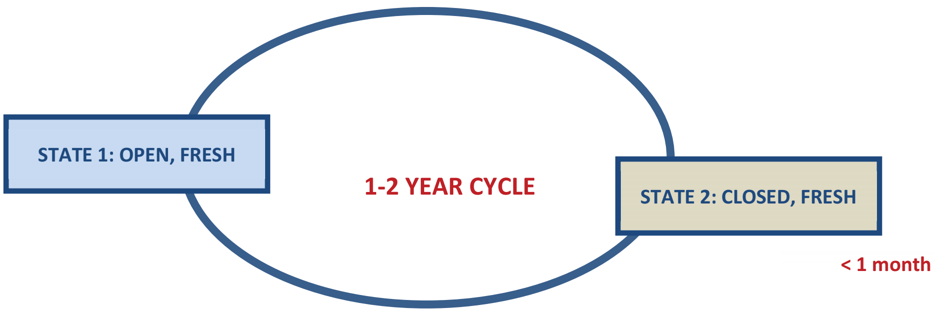


Figure G.1: uMgobezeleni: Typical temporal patterns in the distribution of abiotic states (present)

Mgobezeleni Estuarine Lake system shows very little complexity in its abiotic conditions, which is largely driven by its mouth state. The system is also further buffered through groundwater input that shows seasonal cycle. The system is predominantly in an open mouth state, with closed conditions generally disrupted within days to weeks of closure.

Thus, only two abiotic states (Table G.6) have been identified in the system, with *State 1: Open, fresh* associated with open mouth conditions as reflected in water levels below 1.3 m MSL and formation of brackish conditions in the tidal, if somewhat perched, inlet channel (15-20); while Mgobezeleni and Shazibe (Zone B and C) remain fresh. Under *State 2: Closed, fresh* there is no free connection with the sea, and water levels thus above 1.3 m MSL. Salinity in the inlet (Zone A) is between 5 and 10, while the main water bodies (Zone B and C) remain fresh.

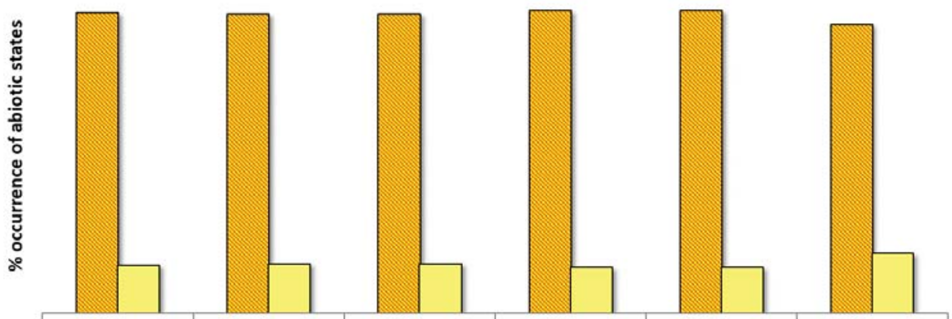
Table G.6: uMgobezeleni: Key abiotic characteristics associated with various states (present)

STATE	PARAMETER	ZONE A: INLET	ZONE B: UMGOBEZELENI	ZONE C: SHAZIBE
State 1: Open, fresh	WL:	0.8-1.3	<1.3	
	Salinity:	15-20	0	0
	Temp:	Summer: 24-27°C; Winter 19-24°C		
	WQ:	NN (1)	MM	MM
State 2: Closed, fresh	WL:	>1.3		
	Salinity:	5-10	0	0
	Temp:	Summer: 24-27°C; Winter 19-24°C		
	WQ:	NN(2)	MM	MM

Groundwater flowing to the lakes has elevated the nutrient levels in those systems as a result of both population increase and introduction of water-borne sewage systems and pit latrines. A large swamp just upstream of the estuary is considered to act as a filter, resulting in improved water quality in the estuary (Bate et al. 2016).

G.2.2 Responses to climate change scenarios

The uMgobezeleni largely responds to groundwater and direct precipitation on the system. The system was evaluated at the desktop level. A broad evaluation of change in freshwater predicts a decrease in flows under the mid future conditions and an increase under the far future conditions. Predicted changes in hydrodynamic functioning, average water level, salinity and marine connectivity are captured in the overall occurrence of different abiotic states in the uMgobezeleni are summarised in Figure G.2. While there are significant changes in the freshwater input between the scenarios most of these changes occur in the flow ranges associated with State 1: Open Fresh, and thus, do not translate into significant shifts in the hydrodynamics of the system.



	Natural	Present	Sc1: RCP 4.5 Mid	Sc 2: RCP 4.5 Far	Sc 3: RCP 8.5 Mid	Sc 4: RCP 8.5 Far
State 1: Open Fresh	86.3	85.8	85.8	86.8	86.8	82.8
State 2: Closed fresh	13.7	14.2	14.2	13.2	13.2	17.2

Figure G.2: uMgobezeleni: Occurrence of different abiotic states estuary under different scenarios

Mouth conditions showed limited sensitivity to the predicted changes in freshwater input under the various scenarios, with Scenario 2 and 3 even moving slight towards natural conditions (Table G.7). Only Scenario 4 reflects some measurable change in spring.

Table G.7: uMgobezeleni: Predicted change in water level (m) under Present State and future Climate Change Scenarios

uMGOBEZELENI:	PRESENT			SCENARIO 1			SCENARIO 2			SCENARIO 3			SCENARIO 4		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
SEASONAL DISTRIBUTION (17 YEAR SIMULATION PERIOD)															
January	0.9	1.3	1.3	0.9	1.3	1.3	0.9	1.3	1.3	0.9	1.3	1.3	0.9	1.3	1.3
February	0.9	1.2	1.2	0.9	1.2	1.2	0.9	1.2	1.2	0.9	1.2	1.2	0.9	1.2	1.2
March	0.9	1.3	1.3	0.9	1.3	1.3	0.9	1.3	1.3	0.9	1.3	1.3	0.9	1.3	1.3
April	0.9	1.2	1.2	0.9	1.2	1.2	0.9	1.3	1.3	0.9	1.3	1.3	0.9	1.2	1.2
May	1.1	1.3	1.3	1.1	1.3	1.3	1.1	1.3	1.3	1.1	1.3	1.3	1.2	1.4	1.4
June	0.9	1.2	1.2	0.9	1.2	1.2	0.9	1.2	1.2	0.9	1.2	1.2	0.9	1.2	1.2
July	0.9	1.2	1.2	0.9	1.2	1.2	0.9	1.2	1.2	0.9	1.2	1.2	0.9	1.2	1.2
August	1.1	1.3	1.3	1.1	1.3	1.3	1.1	1.3	1.3	1.1	1.3	1.3	1.1	1.3	1.3
September	1.0	1.3	1.3	1.0	1.3	1.3	0.8	1.2	1.2	0.8	1.2	1.2	1.2	1.4	1.4
October	1.1	1.4	1.4	1.1	1.4	1.4	1.1	1.4	1.4	1.1	1.4	1.4	1.1	1.4	1.4
November	0.9	1.3	1.3	0.9	1.3	1.3	0.9	1.3	1.3	0.9	1.3	1.3	0.9	1.2	1.2
December	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2
PERCENTILE DISTRIBUTION (17 YEAR SIMULATION PERIOD)															
99%ile	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
95%ile	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
90%ile	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
80%ile	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2
70%ile	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2
60%ile	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2
50%ile (median)	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2
40%ile	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2
30%ile	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2
20%ile	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2
10%ile	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2	0.8	1.2	1.2
1%ile	0.8	1.2	3.0	0.8	1.2	3.0	0.8	1.2	3.0	0.8	1.2	3.0	0.8	1.2	3.0

The salinity regimes under Scenario 1 to 4 are very similar to the present. This is to be expected as the lakes are largely disconnected from the sea through a structure, with changes in salinity now confined to the inlet area. There is a slight decrease in salinity under Scenario 4 in spring. A summary of the result is presented in Table G.8.

Table G.8: uMgobezeleni: Predicted change in salinity under Present State and Future Climate Change Scenarios

uMGOBEZELENI: PRESENT				SCENARIO 1			SCENARIO 2			SCENARIO 3			SCENARIO 4		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
SEASONAL DISTRIBUTION (17 YEAR SIMULATION PERIOD)															
January	14	0	0	14	0	0	14	0	0	14	0	0	14	0	0
February	14	0	0	14	0	0	14	0	0	14	0	0	14	0	0
March	14	0	0	14	0	0	14	0	0	14	0	0	14	0	0
April	14	0	0	14	0	0	14	0	0	14	0	0	14	0	0
May	12	0	0	12	0	0	12	0	0	12	0	0	10	0	0
June	14	0	0	14	0	0	14	0	0	14	0	0	14	0	0
July	14	0	0	14	0	0	14	0	0	14	0	0	14	0	0
August	12	0	0	12	0	0	12	0	0	12	0	0	12	0	0
September	13	0	0	13	0	0	15	0	0	15	0	0	11	0	0
October	11	0	0	11	0	0	11	0	0	11	0	0	11	0	0
November	14	0	0	14	0	0	14	0	0	14	0	0	14	0	0
December	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
PERCENTILE DISTRIBUTION (17 YEAR SIMULATION PERIOD)															
99%ile	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
95%ile	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
90%ile	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
80%ile	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
70%ile	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
60%ile	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
50%ile (median)	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
40%ile	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
30%ile	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
20%ile	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
10%ile	5	0	0	5	0	0	5	0	0	5	0	0	5	0	0
1%ile	5	0	0	5	0	0	5	0	0	5	0	0	5	0	0

Predicted changes in seasonal and percentile distribution of water quality under present and future Climate Change scenarios are provided in Table G.9. Present water quality in the upper lakes of uMgobezeleni system (Zones B and C) has been moderately modified as a result of local diffuse sources, although the lower estuary (Zone A) remain in a near-natural state. However, it is not expected for any of the future Climate Change scenarios to cause marked shifts in water quality from the present.

Table G.9: uMgobezeleni: Predicted change in water quality under Present State and Future Climate Change Scenarios

uMGOBEZELENI: PRESENT				uMGOBEZELEN: SCENARIO 1			uMGOBEZELEN: SCENARIO 2			uMGOBEZELEN: SCENARIO 3			uMGOBEZELEN: SCENARIO 4		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
SEASONAL DISTRIBUTION (SIMULATION PERIOD)															
January	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
February	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
March	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
April	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
May	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
June	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
July	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
August	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
September	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
October	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
November	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
December	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)															
95%ile	2	3	3	2	3	3	2	3	3	2	3	3	2	3	3
90%ile	2	3	3	2	3	3	2	3	3	2	3	3	2	3	3
80%ile	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
70%ile	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
60%ile	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
50%ile (median)	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
40%ile	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
30%ile	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
20%ile	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3
10%ile	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3

G.3 Biotic Responses

G.3.1 Microalgae

The conceptual model for microalgal characteristics under different abiotic scenarios is illustrated in Figure G.3, while the microalgal characteristics associated with different zone are summarised in Table G.10. The uMgobezeleni system is generally characterised by low phytoplankton (~Good: < 5 µg/ℓ) and benthic microalgal (~Good: < 50 mg/m^2) biomass (Bate et al., 2019), primarily due to low nutrient availability, blackwater conditions (low pH) in the estuary (Zone A), as well as resource competition with macrophytes and unsuitable sediment characteristics (macrophyte litter and peat) in the lake systems (Zone B and C). The phytoplankton community in the estuarine inlet is predominantly comprised of small-flagellated taxa (Chlorodendrophyceae and Cryptophyceae) and Bacillariophyceae (diatoms).

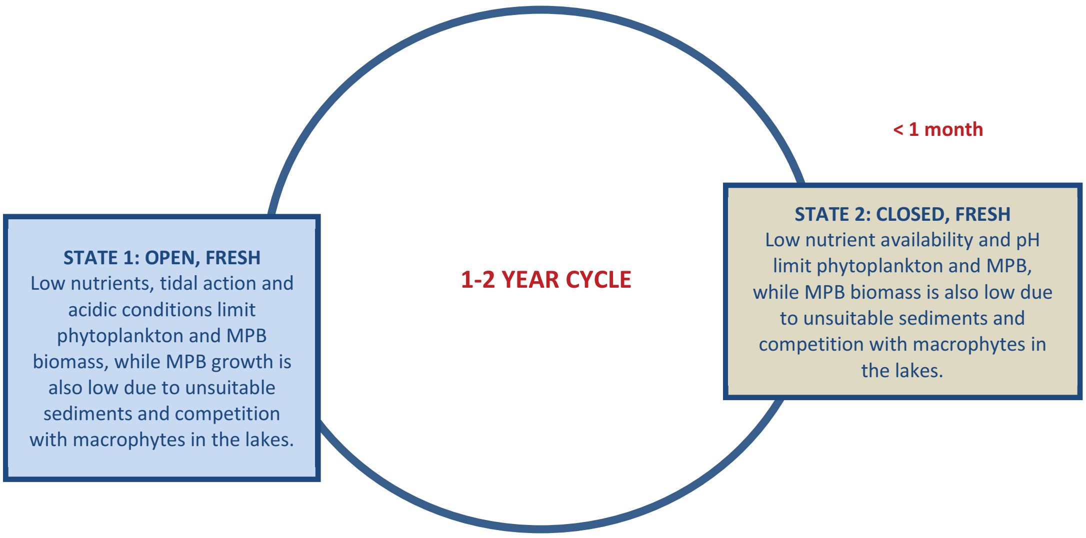


Figure G.3: uMgobezeleni: Microalgae Conceptual model

The lake systems are typically dominated by Cyanophyceae (cyanobacteria), with Chlorophyceae (greens), diatoms, and dinoflagellates also present (but less abundant). The cyanobacterial populations in the lakes have been documented to comprise *Aphanocapsa planktonica*, *Aphanothece* cf. *elabens* and *Microcystis aeruginosa* (all potentially harmful species via toxin production), with Lake uMgobezeleni (Zone B) occasionally supporting dense accumulations.

Table G.10: uMgobezeleni: Key microalgal characteristics associated with various states

STATE	PARAMETER	ZONE A: INLET	ZONE B: UMGOBEZELENI	ZONE C: SHAZIBE
State 1: Open, fresh	Phytoplankton:			
	Benthic microalgae:			
	Harmful algae:			
State 2: Closed, fresh	Phytoplankton:			
	Benthic microalgae:			
	Harmful algae:			

Confidence levels: Phytoplankton – High; Benthic microalgae – Medium; Harmful algae – High

A summary of the key responses in microalgae under the Present State and Future Climate Change scenarios are summarized in Table G.11. Predicted changes in seasonal and percentile distribution of microalgae under present and future Climate Change scenarios are provided in Tables G.12 to G.14.

Table G.11: uMgobezeleni: Predicted change in microalgae under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Phytoplankton and benthic microalgal biomass are typically low due to a lack of in-situ nutrients, blackwater conditions (low pH) in the estuary (Zone A), as well as resource competition with macrophytes and unsuitable sediment characteristics in the lake systems (Zone B and C). However, nutrient-rich groundwater inputs facilitate the occurrence of HAB species in the lake components.
1-3	Scenarios 1-3 are very similar to present and microalgal scores remain the same.
4	Increased temperature and water levels (in Zone C), together with reduced salinity, are expected to increase the prevalence of phytoplankton blooms and harmful freshwater taxa (e.g. cyanobacteria).

Table G.12: uMgobezeleni: Predicted change in Phytoplankton under Present State and Future Climate Change Scenarios

	uMGOBEZELENI: PRESENT			uMGOBEZELEN: SCENARIO 1			uMGOBEZELEN: SCENARIO 2			uMGOBEZELEN: SCENARIO 3			uMGOBEZELEN: SCENARIO 4		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
SEASONAL DISTRIBUTION (SIMULATION PERIOD)															
January	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
February	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
March	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
April	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
May	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
June	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
July	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
August	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
September	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
October	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
November	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
December	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)															
95%ile	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
90%ile	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
80%ile	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
70%ile	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
60%ile	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
50%ile (median)	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
40%ile	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
30%ile	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
20%ile	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3
10%ile	1	3	2	1	3	2	1	3	2	1	3	2	1	4	3

Table G.13: uMgobezeleni: Predicted change in Benthic microalgae under Present State and Future Climate Change Scenarios

	uMGOBEZELENI: PRESENT			uMGOBEZELEN: SCENARIO 1			uMGOBEZELEN: SCENARIO 2			uMGOBEZELEN: SCENARIO 3			uMGOBEZELEN: SCENARIO 4		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
SEASONAL DISTRIBUTION (SIMULATION PERIOD)															
January	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
February	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
March	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
April	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
May	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
June	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
July	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
August	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
September	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
October	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
November	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
December	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)															
95%ile	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
90%ile	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
80%ile	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
70%ile	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
60%ile	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
50%ile (median)	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
40%ile	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
30%ile	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
20%ile	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
10%ile	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1

Table G.14: uMgobezeleni: Predicted change in Harmful algae under Present State and Future Climate Change Scenarios

	uMGOBEZELENI: PRESENT			uMGOBEZELEN: SCENARIO 1			uMGOBEZELEN: SCENARIO 2			uMGOBEZELEN: SCENARIO 3			uMGOBEZELEN: SCENARIO 4		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
SEASONAL DISTRIBUTION (SIMULATION PERIOD)															
January	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
February	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
March	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
April	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
May	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
June	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
July	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
August	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
September	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
October	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
November	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
December	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)															
95%ile	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
90%ile	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
80%ile	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
70%ile	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
60%ile	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
50%ile (median)	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
40%ile	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
30%ile	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
20%ile	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4
10%ile	1	4	3	1	4	3	1	4	3	1	4	3	1	4	4

G.3.2 Macrophytes

The estuary has a diversity of important habitats with strong tropical influences, including swamp forest, mangrove, reeds and sedge swamp. The lower estuary is surrounded on both sides by dune forest. Mangroves (only the black mangrove, *Bruguiera gymnorrhiza)* in combination with the mangrove fern, *Acrostichum aureum* occurred just above the bridge and were some of the largest specimens of this species in South Africa. Inundation, because of bridge construction in the early and late 1970s, resulted in the death of this mangrove stand. This area is now dominated by sedges and reeds, mainly *Phragmites australis, Eleocharis dulcis*, *Cladium mariscus* and *Typha capensis*. The estuary has stands of swamp forest up to 20 m height (Taylor 2016). *Ficus trichopoda* has slowly been replacing the sedge swamp in the floodplain. Submerged macrophytes include *Nymphaea nouchali var. caerulea* and *Stuckenia schweinfurthii* which occur on the outer edge of the swamp forest (Bate et al. 2016, Taylor 2016). The water lily, *Nymphaea lotus* grows in slightly deeper water. Water depth and transparency will influence their abundance. Sea storms can also result in overwash of saline water in the lower reaches causing the dieback of swamp forest and salt-sensitive sedge swamp (Taylor 2016). Lake Shazibe is characterised by reed and sedge swamp, Swamp Forest and submerged macrophytes (*Ceratophyllum demersum*) due to the water transparency (Bate et al. 2016). Both lakes are prone to infestations of aquatic alien vegetation (*Eichhornia crassipes* and *Hydrilla verticillata*) and these will increase should lake nutrient levels rise. The macrophyte conceptual model for uMgobezeleni is presented in Figure G.4.

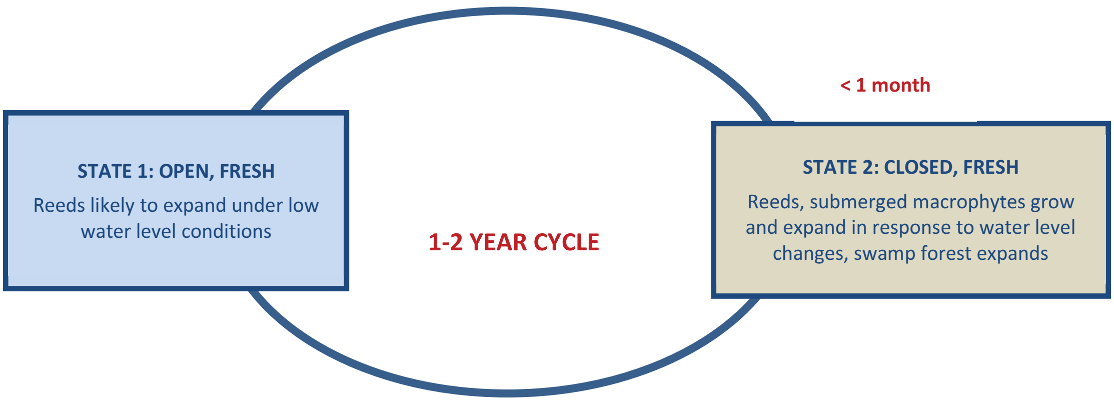


Figure G.4: uMgobezeleni: Macrophyte Conceptual model

December 2016: Mgobezeleni with medium water level – reeds and submerged (in southern section) limited by depth and visibility.

31 May 2011: System closed with some submerged macrophytes present.

22 April 2020: Floating macrophytes, e.g. water level visible in Shazibe as light green along water margin.

Responses of Macrophytes to different scenarios are illustrated in Table G.15. The changes for Scenarios 1 to 3 are small and little change is expected for the macrophytes (Scores remain the same as present at 80) (Table G.16). Increasing water level in Scenario 4 may cause a small decrease in cover of swamp forest, reeds & sedges (score decrease to 75).

Table G.15: uMgobezeleni: Predicted change in macrophytes under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Submerged macrophytes = 22.64 ha Reeds and sedges = 117 ha Swamp forest = 416.65 ha Open water = 80 ha 1 to 2 years closed; < 1 month open
1	MAR reduced by 2 to 5% from present The slight decrease in water level will result in small loss of submerged macrophytes and an increase in reeds and sedges. Macroalgae will increase in summer months.
2	MAR increased by 5 to 10% from present Swamp forest, reeds and sedges will decrease under rising water level especially during spring when natural regrowth occurs.
3	MAR reduced by 2 to 5% from present The slight decrease in water level will result in a loss of submerged macrophytes and swamp forest and an increase in reeds and sedges. Macroalgae will increase as habitat decomposes, especially over summer months.
4	MAR increased by 5 to 10% from present; There is a slight decrease in salinity under Scenario 4 in spring. Salinity changes from a difference of 3.5 to 4.7, therefore 1.2 change. Only in Zone C that water level fluctuation changed from 0.176 to 0.235 (5.9 cm). Swamp forest, reeds and sedges will decrease under rising water level especially during spring when natural regrowth occurs. There is an increase in water level in September, October, and November.

Table G.16: uMgobezeleni: Predicted change in macrophyte under different scenarios (increase=↑ or decrease=↓) from present

SCENARIO	ZONE A	ZONE B	ZONE C
Scenarios 1	Unchanged from present	Unchanged from present	Unchanged from present
Scenario 2	Unchanged from present	Unchanged from present	Unchanged from present
Scenario 3	Unchanged from present	Unchanged from present	Unchanged from present
Scenario 4	Unchanged from present	↑ submerged macrophytes ↓ swamp forest ↓ reeds and sedges	

G.3.3 Fish

The fishes of uMgobezeleni are little studied. The estuary is small but appears to support a good diversity of estuarine species and an unusually high number of juvenile marine fishes. Blaber (1980a) noted that it is the only estuary between St Lucai and Kosi, and this may account for its apparent value as a nursery area. As is the case with the vegetation, human-mediated modification to the system has impacted the fish community. Connectivity between the estuarine reaches at the inlet (Zone A) and Lake uMgobezeleni (Zone B) appears to be very restricted, and even more so in the case of Lake Shazibe (Zone C). Nevertheless, records of some mullet species in the lakes (Bruton 1980b) indicate that the recruitment of marine species into these systems can occur. These might well be chance recruitments, restricted to periods of high flow. Salinity measurements suggest that saline water does not penetrate far up the estuary, and certainly not into these lakes. The fish conceptual model for uMgobezeleni is presented in Figure G.5.

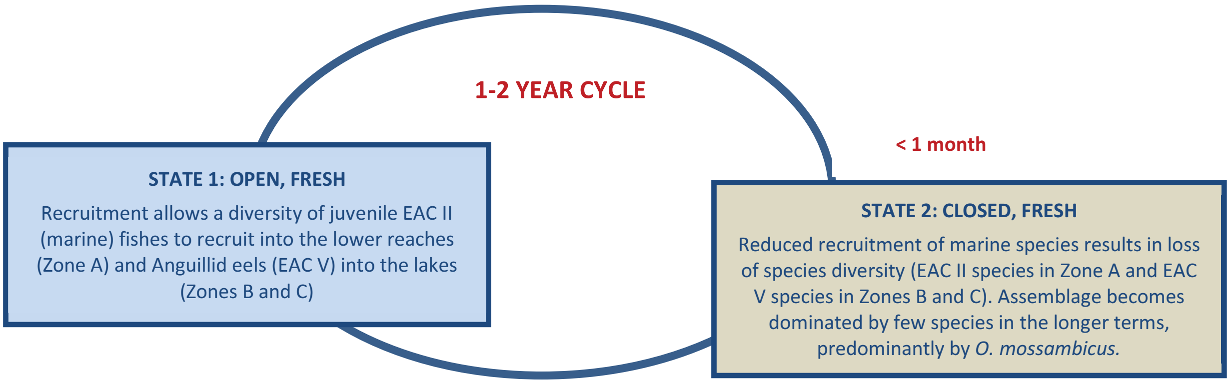


Figure G.5: uMgobezeleni: Fish Conceptual model

Predicted change in fish under present and various climate change scenarios is provided in Table G.17.

Table G.17: uMgobezeleni: Predicted change in fish under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	The estuary (Zone A) supports the greatest diversity of fishes, and these are dominated by estuarine resident and estuarine dependent marine species. Their occurrences can be sporadic in the system depending on recruitment and a high degree of variability can be expected in this assemblage. Consistent features will include *Gilchristella aesturia*, *Ambassis* spp., and various goby species (estuarine residents), and Mugiliidae, *Monodactylus* spp. and *Rhabdosargus holubi* (estuarine dependent marine species). Fish communities in these lakes (Zones B and C) are dominated Cichlidae, but also include gobies in abundance, several small *Barbus* and *Aplocheilichtys* species. From available literature the lakes support few marine spawning species, with occurrences limited to a few of the Mugilidae species, oxeye tarpon (*Megalops cypribiodes*) and Angillidae eels. The lakes also support few estuarine resident species, apparently limited to *Eleotris melanosome* (which in all likelihood is completing its life cycle in these freshwater reaches).
1	Little change anticipated based on predicted changes in mouth state, water level, freshwater flows, water quality and vegetation changes.
2	Little change anticipated based on predicted changes in mouth state, water level, freshwater flows, water quality and vegetation changes.
3	Little change anticipated based on predicted changes in mouth state, water level, freshwater flows, water quality and vegetation changes.
4	Little change anticipated based on predicted changes in mouth state, water level, freshwater flows, water quality and vegetation changes. However, some thermal stress is likely under predicted long term temperature changes. These are difficult to predict but can be expected to be most extreme in the estuary (Zone A) given the small size of this basin. The shallowness of the system precludes the use of deeper water as a refuge from predicted high temperatures. The estuarine resident assemblage will suffer the greatest impacts as eggs and larvae are likely to be the especially vulnerable life stages. Moreover, recruitment of this group of fishes after being lost from the system is likely to be slower than recruitment for marine spawned fishes.

H. KOSI

H.1 Predicted Climate Change Scenarios

Predicted climate change scenarios for RCP 4.5 and 8.5 under mid and far future scenarios relevant to the Kosi System, are presented in Tables H.1 to H.3 for precipitation in the catchment, precipitation in EFZ and ambient atmospheric temperature, respectively. A summary of broad measures of hydrological changes, as reported by Cullis et al. (2015), is provided in Table H.4.

Table H.1: Kosi: Predicted change (%) in precipitation in catchment for RCP 4.5 and 8.5 under mid- and far-future scenarios

CATCHMENT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	4	-18	22	-19	6	-11	4	-19	-7	-2	23	27
RCP 4.5 Far	9	-11	36	-25	13	-33	9	7	-26	29	24	20
RCP 8.5 Mid	12	-28	27	-18	19	-25	7	21	14	-12	-2	14
RCP 8.5 Far	7	-10	41	-5	-8	-13	10	-23	-44	-14	10	52

Table H.2: Kosi: Predicted change (%) in precipitation in EFZ for RCP 4.5 and 8.5 under mid- and far-future scenarios

ESTUARY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	9	-14	24	-16	-5	-3	-7	-13	-11	-2	26	29
RCP 4.5 Far	14	-8	41	-19	12	-33	10	13	-25	31	27	20
RCP 8.5 Mid	11	-26	34	-13	14	-13	0	28	9	-14	1	5
RCP 8.5 Far	22	-10	40	1	-4	-16	6	-18	-44	-12	15	62

Table H.3: Kosi: Predicted increase in ambient atmospheric temperature (°C) for RCP 4.5 and 8.5 under mid- and far-future scenarios

Tave	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RCP 4.5 Mid	1.7	1.8	1.4	1.7	2.1	1.8	2.5	2.2	1.9	1.8	1.1	1.6
RCP 4.5 Far	1.8	2.2	2.0	2.0	2.0	1.9	2.8	2.2	2.9	2.7	1.1	1.9
RCP 8.5 Mid	1.9	2.2	2.1	2.6	2.3	2.4	2.8	2.0	2.2	2.6	1.7	2.2
RCP 8.5 Far	4.1	4.0	4.2	4.3	5.0	4.7	4.8	4.3	5.1	5.1	4.1	4.3
Tmax	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	1.9	1.7	1.6	1.7	1.8	1.7	2.1	2.2	2.1	1.8	0.9	1.6
RCP 4.5 Far	1.9	2.2	2.0	1.9	1.8	1.8	2.4	2.2	3.3	2.7	1.0	1.9
RCP 8.5 Mid	2.0	2.2	2.1	2.5	1.9	2.2	2.3	2.1	2.0	2.7	1.5	2.2
RCP 8.5 Far	3.8	3.8	3.9	4.1	4.3	4.2	4.0	4.1	5.3	5.2	4.0	4.2
Tmin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
RCP 4.5 Mid	1.4	1.8	1.3	1.6	2.5	1.9	2.9	2.2	1.7	1.9	1.4	1.6
RCP 4.5 Far	1.8	2.1	2.0	2.0	2.3	1.9	3.1	2.3	2.4	2.6	1.3	2.0
RCP 8.5 Mid	1.7	2.1	2.1	2.7	2.6	2.5	3.3	1.9	2.5	2.4	2.0	2.2
RCP 8.5 Far	4.4	4.2	4.4	4.4	5.7	5.2	5.5	4.6	4.9	4.9	4.1	4.4

Table H.4: Kosi: Summary of broad measures of hydrological change (as reported by Cullis et al. 2015), including extreme events

PARAMETER	PERCENTAGE CHANGE
Median Flows	+5%
Q 1 (Low flows)	0 to -5%
Q 3 (Floods)	+10% to +15%
Min	-20%
Max	+30%
Extreme events	
Droughts	+5%
Cyclones	Cyclones are predicted to increase in occurrence. Assume 10% likelihood of increased cyclones.

Table H.5 provides a broad overview of the predicted freshwater inputs to the Kosi system under the different scenarios considered.

Table H.5: Kosi: Summary of predicted runoff under RCP 4.5 and 8.5 scenarios for mid and far future conditions

SCENARIO NAME	DESCRIPTION	Volume of freshwater input (x 10^6 m^3)	PERCENTAGE REMAINING
Natural	Reference condition	69.08	
Present	Present	63.79	92.3
Scenario 1	RCP 4.5 Mid	57.95	83.9
Scenario 2	RCP 4.5 Far	64.64	93.6
Scenario 3	RCP 8.5 Mid	65.03	94.1
Scenario 4	RCP 8.5 Far	61.74	89.4

H.2 Abiotic Responses

H.2.1 Abiotic states and key characteristics

The characteristic abiotic states (and associated distinctive temporal patterns) for Kosi are illustrated conceptually in Figure H.1.

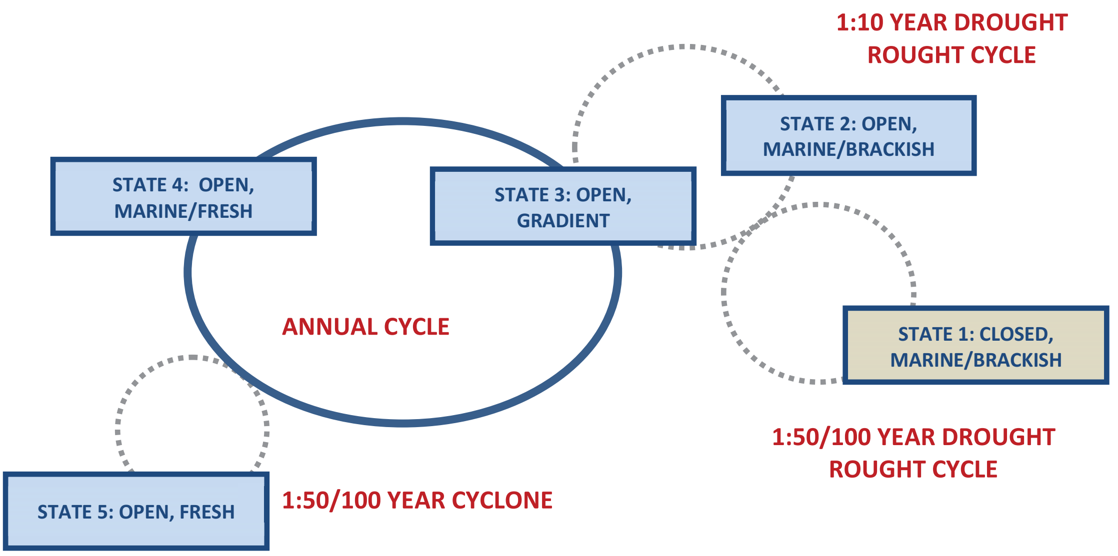


Figure H.1: Kosi: Typical temporal patterns in the distribution of abiotic states (present)

Five abiotic states have been identified in the Kosi Estuarine Lake systems (modified from DWS 2016). Similar to uMgobezeleni, this groundwater-fed system cycle through two states, *State 3: Open, gradient* and *State 4: Open,* *marine/fresh,* at annual timescales. However, two more states were associated with drought conditions, *State 1: Closed, marine/brackish* that occurs under extreme droughts (return period 1:50 to 1:100 years) and *State 2: Open, marine/ brackish* that occurs under decadal-scale drought conditions. In addition*, State 5: Open, fresh,* is associated with the occurrence of episodic cyclonic rainfall events (return period 1: 50 to 1:100 years).

During State 1: Closed, marine/brackish the mouth is closed for weeks to months at a time, with water levels above that of sea level as a result of back flooding (1.5-2.5 m). The system shows a strong marine influence varying from 30 near the mouth (Zone A) to 5 in Lake Nhlange (Zone D). In *State 2: Open, marine/ brackish* the system shows a strong marine influence due to reduced freshwater inflow over a long period. Marine influence is detected in all lakes with Makhawulani (Zone B) at 30 to 35, Mpungwini (Zone C) at 25, Nhlange (Zone D) at 15 and Amanzimnyana (Zone E) at 5. Lake levels are at sea level or slightly below. Under *State 3: Open, gradient* the marine influence is detected in all lakes with Makhawulani (Zone B) at 30 to 35, Mpungwini (Zone C) at 20, Nhlange (Zone D) at 5 and Amanzimnyana (Zone E) at 1. Lake levels are similar to that of sea level. Strong tidal flows observed. *State 4: Open, marine/fresh* is associated with the wet season with the upper two lakes (Zones D and E) fresh, and marine influence confined to the lower two lakes, Makhawulani (Zone B) and Mpungwini (Zone C). Under this scenario there is a seasonal decline in salinity to 25 in Makhawulani (Zone B), and to 15 in Mpungwini (Zone C) at 15. Lake levels are at sea level or slightly above. Strong tidal flows are observed. In *State 5: Open, fresh* a weak marine influence is confined to the lower lakes. Salinity in Makhawulani (Zone B) is 15 and in Mpungwini (Zone C) is 10. In this state strong stratification develops in these lakes, with surface salinity fresh to brackish. Lake levels are elevated above sea level (> 2.0 m) with a strong net outflow.

Predicted changes in seasonal and percentile distribution of water quality under present and future Climate Change scenarios are provided in Table H.6. Inorganic nitrogen (mainly NO_x-N) concentrations are low throughout the system, and are near depleted in most lakes, except Lakes Makhawulani and Mpungwini. This suggests that there is no significant 'new' NO_x-N nutrient entering the system and that which does enter the system is utilised effectively with a resultant near-depleted/low NO_x-N concentrations. Inorganic total ammonia (NH_3-N plus NH_4-N) concentrations are also relatively low, but higher than NO_x-N, except for isolated high values associated with lower oxygen bottom waters in some channels and lakes. In the Kosi system there is no large urban development directly adjacent to the estuary (e.g. direct sewage inputs) and the presence of total Ammonia-N can typically be associated with remineralisation processes. However, low concentrations are indicative that such *in situ* processes remain within the natural nutrient/primary productivity balance of the system. The lower estuary and shallower lakes (Lakes Nhlange and Amanzimnyana) are generally well-oxygenated throughout, while the deeper lakes (Lakes Makhawulani and Mpungwini) show naturally lower DO in bottom waters, particularly during periods of strong stratification at 5-10 m water depth, such as is the case during stronger freshwater inflows (DWS 2016).

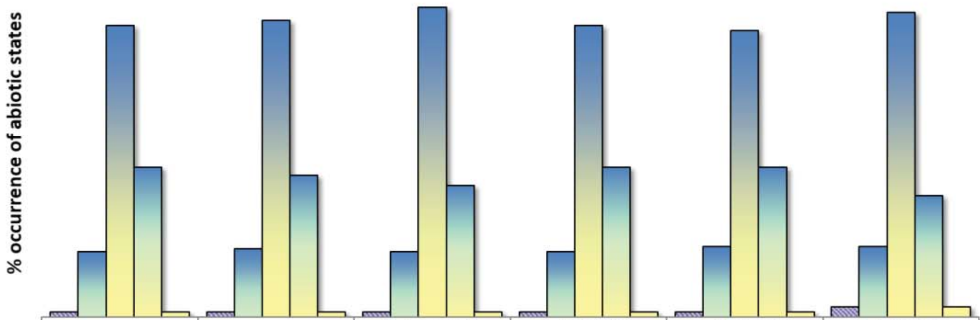
Table H.6: Kosi: Key abiotic characteristics associated with various states

STATE	PARAMETER	ZONE A: LOWER ESTUARY	ZONE B: MAKHAWULANI	ZONE C: MPUNGWINI	ZONE D: NHLANGE	ZONE E: AMANZIMNYANA
State 1: Closed, marine/brackish	WL:	1.5-2.5				
	Salinity:	30	25	20	5-10	1
	Temp:	Summer – 22-30°C ; Winter – 18-21°C				
	WQ:	NN(2)	NN(2) naturally hypoxic in bottom layer	MM naturally lower DO in bottom layer (~5)	MM	MM
State 2: Open, marine/ brackish	WL:	0.3-1.3 (tidal)	<0.6			
	Salinity:	35	34	25	15	5
	Temp:	Summer – 22-30°C ; Winter – 18-21°C				
	WQ:	NN(1)	NN(1) naturally hypoxic in bottom layer	NN(2) naturally lower DO in bottom layer (~5)	NN(2)	NN(2)
State 3: Open, gradient	WL:	0.3-1.3 (tidal)	<0.6			
	Salinity:	35	30	20	5	1
	Temp:	Summer – 22-30°C ; Winter – 18-21°C				
	WQ:	NN(1)	NN(1) naturally hypoxic in bottom layer	NN(2) naturally lower DO in bottom layer (~5)	NN(2)	NN(2)

STATE	PARAMETER	ZONE A: LOWER ESTUARY	ZONE B: MAKHAWULANI	ZONE C: MPUNGWINI	ZONE D: NHLANGE	ZONE E: AMANZIMNYANA
State 4: Open, marine/fresh	WL:	0.3-1.3 (tidal)	0.6-1.5			
	Salinity:	**35**	**25**	**15**	**0**	**0**
	Temp:	Summer – 22-30°C ; Winter – 18-21°C				
	WQ:	**NN(1)**	**NN(1)** naturally hypoxic in bottom layer	**NN(2)** naturally hypoxic in bottom layer	**NN(2)**	**NN(2)**
State 5: Open, fresh	WL:	0.3-1.3 (tidal)	> 2.0			
	Salinity:	20	15	10	0	0
	Temp:	Summer – 22-30°C ; Winter – 18-21°C				
	WQ:	NN(1)	NN(2) naturally hypoxic in bottom layer	NN(2) naturally hypoxic in bottom layer	NN(2) NN(1)*	NN(2)

H.2.2 Responses to climate change scenarios

The Kosi Estuary responds predominantly to groundwater inflow and direct rainfall. Surface water inflows only make a small contribution to the overall freshwater input to the system. In addition to changes in climate, this study also explored two additional scenarios at the desktop level, namely Scenario 5: Storm induced Bhanga Nek breakthrough into Nhlange (Lake 3) and Scenario 6: Sea Level Rise impacts. **No systematic modelling was undertaken for these aspects, but the intent was to establish to what extend the ecology of Kosi was sensitive to these possible impacts**. Predicted changes in hydrodynamic functioning, average water level, salinity and marine connectivity are captured in the overall occurrence of different abiotic states in the Kosi System are summarised in Figure H.2.



	Natural	Present	Sc1: RCP 4.5 Mid	Sc 2: RCP 4.5 Far	Sc 3: RCP 8.5 Mid	Sc 4: RCP 8.5 Far
State 1: Closed Marine/brackish	1.0	1.0	1.0	1.0	1.0	2.0
State 2: Open Marine/brakish	12.7	13.2	12.7	12.7	13.7	13.7
State 3: Open Gradient	56.4	57.4	59.8	56.4	55.4	58.8
State 4: Open Marine/fresh	28.9	27.4	25.5	28.9	28.9	23.5
State 5: Open Fresh	1.0	1.0	1.0	1.0	1.0	2.0

Figure H.2: Kosi: Occurrence of different abiotic states in the Kosi Estuary under different scenarios

Mouth closure in Kosi has only been observed under extreme drought conditions. The risk of State 1 occurring is 1% for Present and Scenarios 1 to 3 (Table H.7). Under Scenario 4 the risk of mouth closure increases to > 2%. Note, the knock-on effect of increased evapotranspiration and groundwater use due to elevated temperatures has not been factored in the water balance models used here, so the real-world risk of mouth closure may be higher, especially under the ongoing development of commercial forest plantations in the region. Mouth closure period varies from 6 weeks to 6 months under Present and Scenario 1 to 3 conditions, but can be as long as 1 or 2 years under Scenario 4 depending the variability in precipitation.

Table H.7: Kosi: Summary of potential change in mouth stat under future climate change, coastal erosion and sea level rise scenarios

SCENARIO	DESCRIPTION	MOUTH CLOSURE
Natural	Reference condition	Risk of closure: <1% of the time, remaining closed for 3 to 12 weeks
Present	Present	Risk of closure: >1% of the time, remaining closed for 6 weeks to 6 months
Scenario 1	RCP 4.5 Mid	Risk of closure: >1% of the time, remaining closed for 6 weeks to 6 months
Scenario 2	RCP 4.5 Far	
Scenario 3	RCP 8.5 Mid	
Scenario 4	RCP 8.5 Far	Risk of closure: 2-3% of the time, remaining closed for a few months to 2 years

Under Scenario 5 a second mouth forms at Bhanga Nek that directly links Lake 3 to the sea. It is highly likely that during this period Kosi may even close for a period depending on freshwater input, as the presence of two mouths will reduce outflows significantly and thus reduce related scouring of flood tide induced marine sediment on the ebb tide. Under Scenario 6 elevated sea levels may enhance tidal flows through the mouth and likely assist in maintaining open mouth conditions, thus reducing the risk of mouth closure from the present.

Water levels under Scenarios 1 to 3 are like the present (Table H.8). Average water levels decrease by about 10 cm under Scenario 4. A broad summary of predicted water levels is provided below in Table B.8. Under Scenario 5, Zone D (Lake Nlange) will become the predominant tidal part of the system, with Zones A, B, C and D mostly responding to the neap-spring cycle. Under Scenario 6, tidal ranges are likely to be similar to the present, with even a small increase in tidal range possible as the high-water levels will result in less tidal constrictions, thus resulting in some loss of lake segmentation, especially in the case of the lower lakes.

Table H.8: Kosi: Predicted water level (m) under Present State and Future Climate Change Scenarios

KOSI:	PRESENT					SCENARIO 1					SCENARIO 2					SCENARIO 3					SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (17 YEAR SIMULATION PERIOD)																									
January	0.6	1.1	1.1	1.1	0.0	0.6	1.1	1.1	1.1	1.1	0.6	1.2	1.2	1.2	1.1	0.6	1.1	1.1	1.1	1.1	0.6	1.2	1.2	1.2	1.1
February	0.6	1.2	1.2	1.2	0.0	0.6	1.0	1.0	1.0	1.0	0.6	1.2	1.2	1.2	1.0	0.6	1.1	1.1	1.1	1.0	0.6	1.1	1.1	1.1	1.0
March	0.6	1.0	1.0	1.0	0.0	0.6	0.8	0.8	0.8	0.8	0.6	1.0	1.0	1.0	0.8	0.6	0.9	0.9	0.9	0.8	0.6	1.0	1.0	1.0	0.8
April	0.6	0.9	0.9	0.9	0.0	0.6	0.7	0.7	0.7	0.7	0.6	0.8	0.8	0.8	0.7	0.6	0.9	0.9	0.9	0.7	0.6	0.9	0.9	0.9	0.7
May	0.6	0.6	0.6	0.6	0.0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
June	0.6	0.7	0.7	0.7	0.0	0.6	0.7	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.7
July	0.6	0.8	0.8	0.8	0.0	0.6	0.8	0.8	0.8	0.8	0.6	0.7	0.7	0.7	0.8	0.6	0.8	0.8	0.8	0.8	0.6	0.7	0.7	0.7	0.8
August	0.6	0.6	0.6	0.6	0.0	0.6	0.7	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.7
September	0.6	0.7	0.7	0.7	0.0	0.6	0.7	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.7
October	0.6	0.7	0.7	0.7	0.0	0.6	1.0	1.0	1.0	1.0	0.6	0.9	0.9	0.9	1.0	0.6	0.8	0.8	0.8	1.0	0.6	0.6	0.6	0.6	1.0
November	0.6	1.1	1.1	1.1	0.0	0.6	1.0	1.0	1.0	1.0	0.6	1.0	1.0	1.0	1.0	0.6	1.1	1.1	1.1	1.0	0.6	0.9	0.9	0.9	1.0
December	0.6	1.0	1.0	1.0	0.0	0.6	0.9	0.9	0.9	0.9	0.6	1.0	1.0	1.0	0.9	0.6	1.1	1.1	1.1	0.9	0.6	1.0	1.0	1.0	0.9
PERCENTILE DISTRIBUTION (17 YEAR SIMULATION PERIOD)																									
99%ile	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5
95%ile	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5
90%ile	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5
80%ile	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5	0.6	1.5	1.5	1.5	1.5
70%ile	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.6	0.6	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6
60%ile	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
50%ile (median)	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
40%ile	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
30%ile	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
20%ile	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
10%ile	0.6	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.5
1%ile	3.0	3.0	3.0	3.0	4.0	3.0	3.0	3.0	3.0	4.0	3.0	3.0	3.0	3.0	4.0	3.0	3.0	3.0	3.0	4.0	3.0	3.0	3.0	3.0	4.0

A summary of the salinity regimes under different scenarios is presented in Table H.11. Salinity regimes under Scenario 1 to 3 are very similar to the present. However, there is an increase in salinity under Scenario 4, especially in Lake Nhlane (Lake 4, Zone D). Under Scenario 5 the development of the second mouth will cause a catastrophic shift in salinity regimes in the system, with Nhlange becoming nearly marine dominated (25-30). This saline water, in turn, will be tidally advected into the neighbouring lakes, Amanzimnyama (Zone E) and Mpungwini (Zone C), elevating salinities to near-permanent brackish conditions. Initially, high salinity water will enter the system from both mouths, thus elevating salinity significantly in Makhawulani (Zone B) as well as Mpungwini (Zone C). Once the present mouth closes, as predicted, a gradient will develop with Zone B salinities more likely than not <5. Under Scenario 6 there will be an increase in marine water tidally forced into the system and very likely lead to an overall increase in salinity penetration. This poses a significant risk in Amanzimnyama (Zone E), which is a freshwater system with little to no salinity penetration at present.

Table H.9: Kosi: Predicted salinity under Present State and Future Climate Change Scenarios

KOSI:	PRESENT					SCENARIO 1					SCENARIO 2					SCENARIO 3					SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (17 YEAR SIMULATION PERIOD)																									
January	35	28	18	3	1	35	28	18	3	1	35	27	17	3	1	35	28	18	3	1	35	27	17	3	1
February	35	27	17	2	1	35	28	18	3	1	35	27	17	2	1	35	28	18	3	1	35	28	18	3	1
March	35	28	19	4	1	35	29	19	5	1	35	29	19	5	1	35	29	19	5	1	35	29	19	5	1
April	35	29	19	4	1	35	30	20	6	1	35	29	19	4	1	35	29	19	4	1	35	29	19	4	1
May	35	31	21	8	2	35	32	22	9	2	35	31	21	8	2	35	31	21	8	2	35	31	21	8	2
June	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1
July	35	29	19	5	1	35	29	19	5	1	35	30	20	5	1	35	29	19	5	1	35	30	20	5	1
August	35	31	21	8	2	35	30	21	7	2	35	30	21	7	2	35	31	21	8	2	35	31	21	8	2
September	35	30	20	6	2	35	30	20	6	2	35	30	20	6	2	35	30	20	6	2	35	31	21	7	2
October	35	31	21	8	2	35	28	19	4	2	35	29	20	6	2	35	30	20	7	2	35	31	21	8	2
November	35	28	18	4	1	35	28	19	4	1	35	28	19	4	1	35	28	18	4	1	35	29	19	4	1
December	35	28	18	3	1	35	29	19	4	1	35	28	18	3	1	35	27	17	2	1	35	28	18	3	1
PERCENTILE DISTRIBUTION (17 YEAR SIMULATION PERIOD)																									
99%ile	20	15	10	0	0	20	15	10	0	0	20	15	10	0	0	20	15	10	0	0	20	15	10	0	0
95%ile	35	34	25	15	5	35	34	25	15	5	35	34	25	15	5	35	34	25	15	5	35	34	25	15	5
90%ile	35	34	25	15	5	35	34	25	15	5	35	34	25	15	5	35	34	25	15	5	35	34	25	15	5
80%ile	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1
70%ile	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1
60%ile	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1
50%ile (median)	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1
40%ile	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1	35	30	20	5	1
30%ile	35	30	20	5	1	35	30	20	5	1	35	30	20	4	1	35	30	20	4	1	35	30	20	5	1
20%ile	35	25	15	0	0	35	25	15	0	0	35	25	15	0	0	35	25	15	0	0	35	25	15	0	0
10%ile	35	25	15	0	0	35	25	15	0	0	35	25	15	0	0	35	25	15	0	0	35	25	15	0	0
1%ile	30	25	20	10	1	30	25	20	10	1	30	25	20	10	1	30	25	20	10	1	30	25	20	10	1

Present water quality in the Kosi system is mostly still in a near-natural state, except in the upper lake (Zone E) where some nutrients are elevated. However, it is not expected for any of the future Climate Change scenarios to cause marked shifts in water quality from the present (Table H.10).

Table H.10: Kosi: Predicted water quality under Present State and Future Climate Change Scenarios

KOSI: PRESENT						KOSI: SCENARIO 1					KOSI: SCENARIO 2					KOSI: SCENARIO 3					KOSI: SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																									
January	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
February	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
March	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
April	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
May	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
June	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
July	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
August	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
September	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
October	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
November	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
December	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																									
95%ile	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
90%ile	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
80%ile	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
70%ile	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
60%ile	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
50%ile (median)	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
40%ile	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
30%ile	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
20%ile	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
10%ile	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2

H.3 Biotic Responses

H.3.1 Microalgae

The conceptual model for microalgal characteristics under different abiotic scenarios is illustrated in Figure H.3.

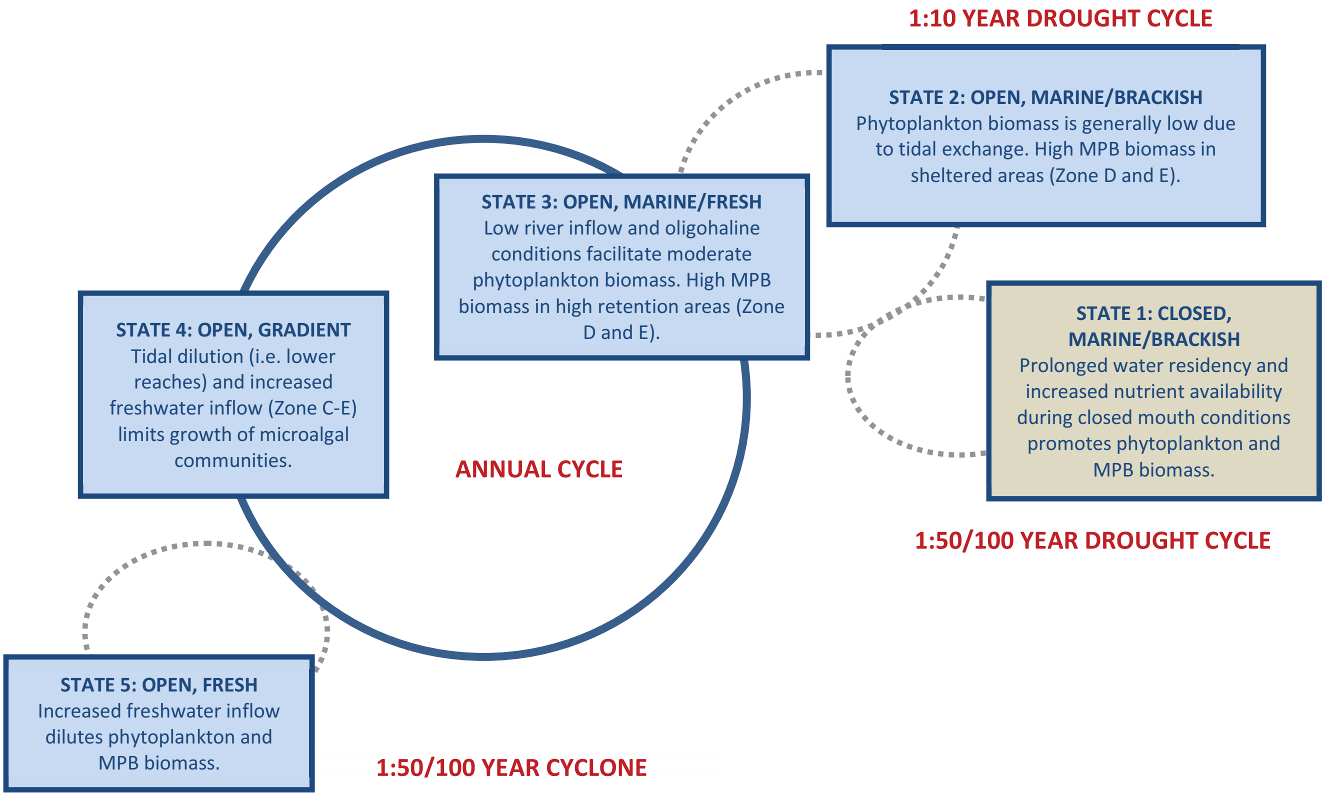


Figure H.3 Kosi: Microalgae Conceptual model

Phytoplankton biomass concentrations in the Kosi Estuarine Lake typically reflect oligotrophic (~Good: <5 µg/ℓ) conditions in the tidally influenced Zones A-C, with mesotrophic (~Fair: ≥ 5 but < 20 µg/ℓ) levels characteristic of the oligohaline (<5) lakes situated furthest from the mouth (Zone D and E). Cyanophyceae (cyanobacteria), and to a lesser degree Chlorophyceae (greens), are the most abundant groups in freshwater conditions (Zone D and E) that are typical of all the designated states, excluding State 2 (open, marine/brackish). Dominant cyanophyte species present in Lake Mpungwini and Nhlange include *Merismopedia* sp., *Microcystis* spp., *Aphanothece* sp., and *Chroococcus* sp.; whilst *Oocystis* sp. and *Dictyosphaerium* sp. are the dominant greens present in Kosi Bay. Flagellated taxa (e.g. Cryptophyceae and Chlorodendrophyceae), bacillariophytes (diatoms) and dinoflagellates are dominant in the brackish/marine portions of the system (Zone A-C). Recent research in the system (DWS, 2016) showed that benthic microalgal biomass is highest in Zone E (441.13 ± 94.43 mg/m^2) and lowest in Zone B (51.14 ± 14.45 mg/m^2), while the average benthic chlorophyll *a* for all sites was 130.1 ± 22.88 mg/m^2 (~Poor: ≥ 100 mg/m^2). These conditions coincide with periods of low river inflow (increased water residency) and longitudinal salinity gradients (State 1-3). Additionally, sheltered sediments (less resuspension) generally supported elevated MPB levels compared to exposed, non-cohesive sands and silts.

Numerous data sets collected from the Kosi system (2014, 2015 and 2016) consistently showed relatively high MPB concentrations throughout the system, even along the well flushed lower reaches (Zone A). This suggested that MPB within this system may be anomalous to typical estuarine condition ranges (Table 2.3) and these ranges were therefore adjusted for Kosi (Table H.11). The role of groundwater nutrient supply may also play a role and should be investigated.

Table H.11: Adjusted microalgae index for Kosi to estimate conditions under various abiotic states and scenarios, expressed as modification from reference (adapted from Lemley et al. 2015; Turpie et al. 2015)

SIMPLIFIED CATEGORY	BENTHIC MICROALGAE (KOSI ONLY)
Natural/ Near-natural (NN)	Phytoplankton: < 5 µg/ℓ
	Benthic microalgae: < 125 mg/m^2
	HABs: Not present
Moderately Modified (MM)	Phytoplankton: ≥ 5 but < 20 µg/ℓ
	Benthic microalgae: ≥ 125 but < 250 mg/m^2
	HABs: Possibly present
Heavily Modified (HM)	Phytoplankton: ≥ 20 but < 60 µg/ℓ
	Benthic microalgae: ≥ 250 but < 375 mg/m^2
	HABs: Present
Severely/Critically Modified (SM)	Phytoplankton: ≥ 60 µg/ℓ
	Benthic microalgae: ≥ 375 mg/m^2
	HABs: Abundantly present

The microalgae characteristics associated with different zone are summarised in Table H.12 (see Table H.11).

Table H.12: Kosi: Key microalgal characteristics associated with various states

STATE	PARAMETER	ZONE A: LOWER ESTUARY	ZONE B: MAKHAWULANI	ZONE C: MPUNGWINI	ZONE D: NHLANGE	ZONE E: AMANZIMNYANA
State 1: Closed, marine/brackish	Phytoplankton:					
	Benthic microalgae:					
	Harmful algae:					
State 2: Open, marine/ brackish	Phytoplankton:					
	Benthic microalgae:					
	Harmful algae:					
State 3: Open, gradient	Phytoplankton:					
	Benthic microalgae:					
	Harmful algae:					
State 4: Open, marine/fresh	Phytoplankton:					
	Benthic microalgae:					
	Harmful algae:					
State 5: Open, fresh	Phytoplankton:					
	Benthic microalgae:					
	Harmful algae:					

Confidence levels: Phytoplankton – High; Benthic microalgae – High; Harmful algae – Medium

A summary of the key responses in microalgae under the Present State and Future Climate Change scenarios are summarized in Table H.13. Predicted changes in seasonal and percentile distribution of microalgae under present and future Climate Change scenarios are provided in Tables H.14 to H.16.

Table H.13: Kosi: Predicted change in microalgae under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Phytoplankton biomass is generally low in the tidally influenced Zone A-C, with increases observed in the oligohaline lakes situated furthest from the mouth (Zone D & E). Similarly, potentially harmful freshwater taxa have been recorded in Zone D and E. Benthic microalgae are typically high in sheltered areas, often coinciding with periods of low river inflow, and brackish conditions (Zone D & E).

SCENARIO	SUMMARY OF CHANGES
1-3	With little change predicted for the abiotic environment (e.g. water level, salinity), microalgal scores are expected to be the same as present.
4	Increases in salinity, temperature, and mouth closure, together with reduced water levels, are expected to facilitate increased microalgal growth and HAB occurrence, particularly in the high retention zones (D & E).

Table H.14: Kosi: Predicted Phytoplankton under Present State and Future Climate Change Scenarios

KOSI: PRESENT						KOSI: SCENARIO 1					KOSI: SCENARIO 2					KOSI: SCENARIO 3					KOSI: SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																									
January	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3
February	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3
March	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
April	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
May	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
June	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
July	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
August	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
September	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
October	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
November	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
December	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																									
95%ile	1	1	2	3	3	1	1	2	3	3	1	1	2	3	3	1	1	2	3	3	1	1	2	3	4
90%ile	1	1	2	3	3	1	1	2	3	3	1	1	2	3	3	1	1	2	3	3	1	1	2	3	4
80%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
70%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
60%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
50%ile (median)	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
40%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
30%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	3
20%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3
10%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3

Table H.15: Kosi: Predicted Benthic microalgae under Present State and Future Climate Change Scenarios

KOSI: PRESENT						KOSI: SCENARIO 1					KOSI: SCENARIO 2					KOSI: SCENARIO 3					KOSI: SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																									
January	1	1	1	2	3	1	1	1	2	3	1	1	1	2	2	1	1	1	2	3	2	1	1	3	4
February	1	1	1	2	2	2	1	1	2	3	1	1	1	2	2	1	1	1	2	3	2	1	1	3	4
March	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
April	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
May	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
June	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
July	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
August	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
September	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
October	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
November	1	1	1	2	3	2	1	1	2	3	2	1	1	2	3	1	1	1	2	3	2	1	1	3	4
December	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	1	1	1	2	2	2	1	1	3	4
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																									
95%ile	2	1	1	3	4	2	1	1	3	4	2	1	1	3	4	2	1	1	3	4	2	1	1	3	4
90%ile	2	1	1	3	4	2	1	1	3	4	2	1	1	3	4	2	1	1	3	4	2	1	1	3	4
80%ile	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
70%ile	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
60%ile	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
50%ile (median)	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
40%ile	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
30%ile	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	2	3	2	1	1	3	4
20%ile	1	1	1	2	2	1	1	1	2	2	1	1	1	2	2	1	1	1	2	2	2	1	1	3	4
10%ile	1	1	1	2	2	1	1	1	2	2	1	1	1	2	2	1	1	1	2	2	2	1	1	3	4

Table H.16: Kosi: Predicted Harmful algae under Present State and Future Climate Change Scenarios

KOSI: PRESENT						KOSI: SCENARIO 1					KOSI: SCENARIO 2					KOSI: SCENARIO 3					KOSI: SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (SIMULATION PERIOD)																									
January	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3
February	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3
March	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
April	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
May	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
June	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
July	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
August	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
September	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
October	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
November	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
December	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
PERCENTILE DISTRIBUTION (SIMULATION PERIOD)																									
95%ile	1	1	1	3	3	1	1	1	3	3	1	1	1	3	3	1	1	1	3	3	1	1	2	3	4
90%ile	1	1	1	3	3	1	1	1	3	3	1	1	1	3	3	1	1	1	3	3	1	1	2	3	4
80%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
70%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
60%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
50%ile (median)	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
40%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
30%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	3	4
20%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3
10%ile	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3

H.3.2 Macrophytes

The estuarine lake system is of considerable botanical importance because the salinity gradient that characterises the transition from the lakes to the sea supports nationally important areas of submerged macrophytes, swamp forest, reeds and sedges and mangrove habitat (Figures H.4 and H.5). It has the largest submerged macrophyte extent in the country (652 ha) and second largest area of swamp forest (869 ha). Floating and submerged macrophytes occur in the lakes and include *Ceratophyllum demersum, Stuckenia schweinfurthii* and *Najas marina*. Species more tolerant of brackish to marine conditions occur in Lake 3 such as *Stuckenia pectinata* and *Zostera capensis, Ruppia cirrhosa, while Halodule uninervis* occur in Lake 1 (Zone A, lower estuary). Thick algal mats of *Chara globularis* and *Sprirogyra* sp. are a distinctive feature of the expansive Lake Nhlange. *Lumnitzera racemosa* is the dominant mangrove first appearing in the Mtando channel of Lake Mpungwini. Six species of mangroves occur here with *Bruguiera gymnorhiza* on the southern banks of this lake in more saline conditions whereas islands of *Avicennia marina* are prevalent in the tidal estuary. Mangroves die back under mouth closure due to inundation of aerial roots. In 1966 the mouth closed for five months causing a loss of mangroves. Reeds and sedges include *Phragmites australis, Schoenoplectus scirpoides, Cyperus spp., Cladium mariscus* subspp. *jamaicense* and *Typha natalensis.* Swamp Forest includes *Hibiscus tiliaceus,* various ferns and *Raphia australis*. These species are euryhaline. Salt marsh and saline grasses occur in the low-lying areas around Lake 1 and 2, with saline grasses also occurring on the peninsulas between the lakes. The vegetation exhibits a distinct zonation based on environmental gradients, particularly salinity, along the length of the estuary and laterally along the banks.

The mangrove fern *Acrostichum aureum*, common reed *Phragmites australis*, sedge *Schoenoplectus scirpoides* and freshwater *Hibiscus tilieaceus* show a cosmopolitan distribution occurring throughout the estuary. Height and density of *Phragmites australis* is reduced in response to increasing salinity as it grows best under brackish conditions of 15 (Adams and Bate 1999). Freshwater seeps, such as at the Kosi Lodge launch site, produce dense pockets of reed and sedge habitat. Similarly, increased salinity (24-30) in the mouth region has resulted in the freshwater mangrove *Barringtonia racemosa* replacing the freshwater hibiscus habitat. While water level, mouth status and salinity affect habitat abundance and distribution, groundwater is also an essential factor in maintaining the water table supporting the growth of riparian and micro-habitats along lake margins and banks (DWS 2016). The abstraction of groundwater during dry periods may negatively impact these habitats. Season also affects macrophyte habitats with reed and submerged macrophyte showing biomass reduction during the winter months. The macrophyte conceptual model for Kosi is presented in Figure H.6.

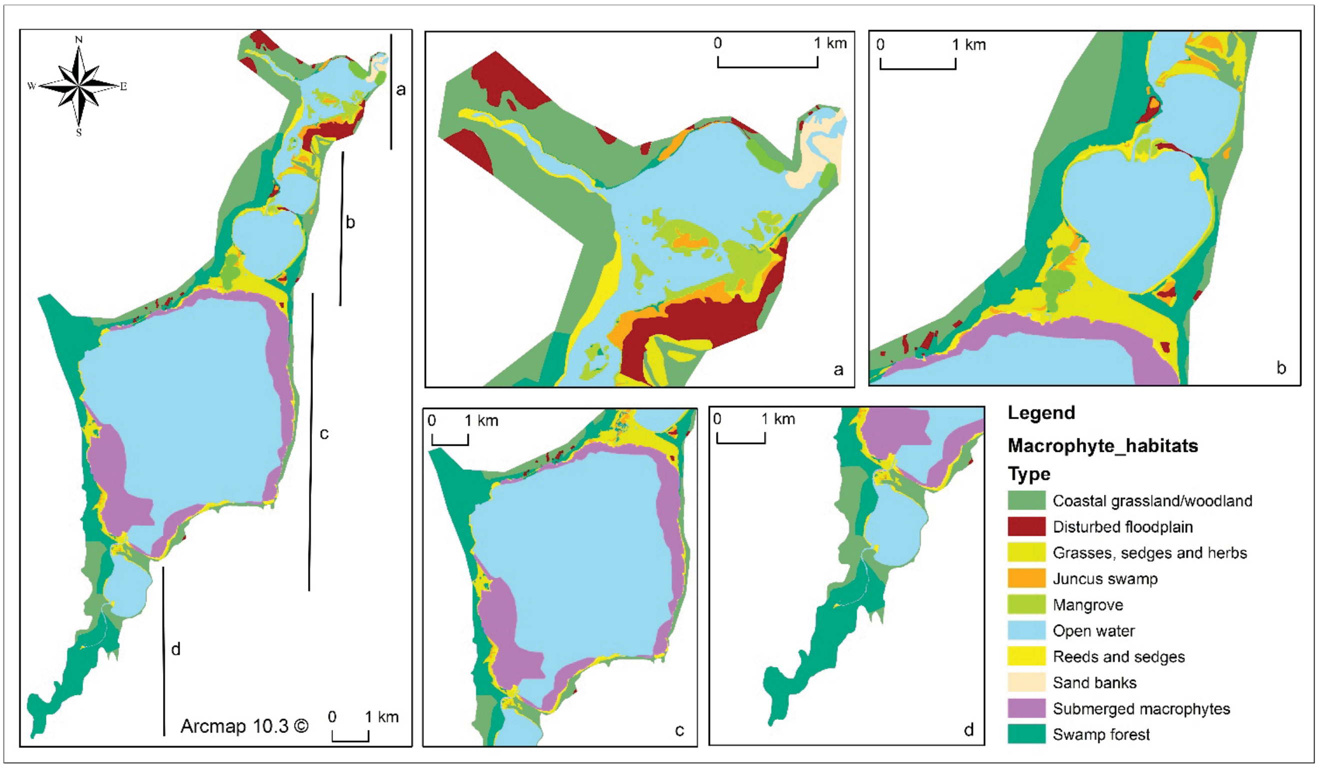


Figure H.4: Kosi: Map of key macrophyte habitats indicating a) Zone A lower estuary b) Zone B Makhawulani & Zone C Mpungwini c) Zone D: Nhlange and d) Zone E: Amanzimnyana

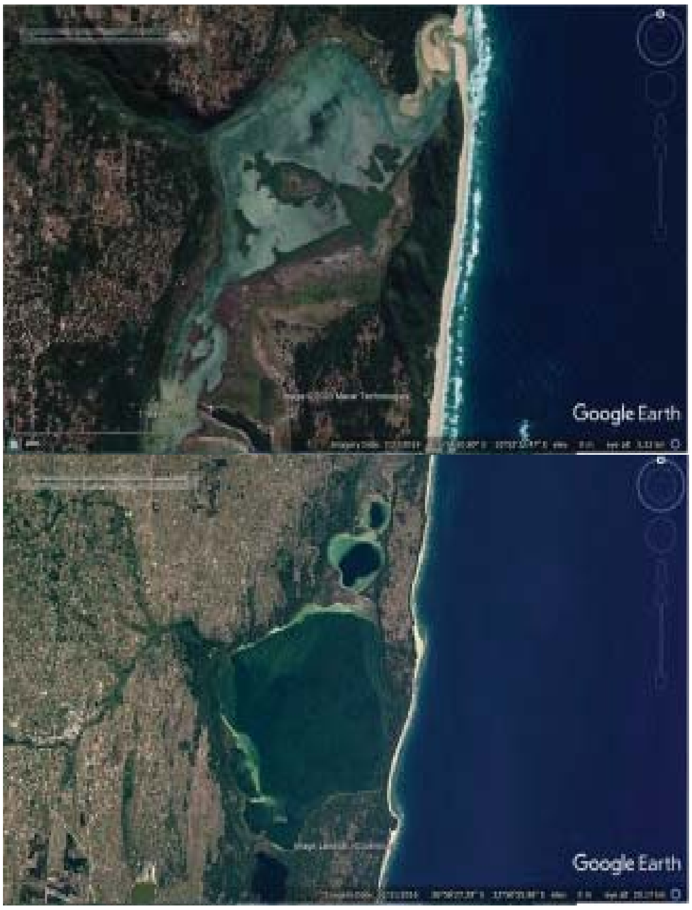


Figure H.5: Kosi: (23 July 2019) Salt marsh and mangroves present in lower reaches, submerged macrophytes, reeds and sedges dominant in the lakes

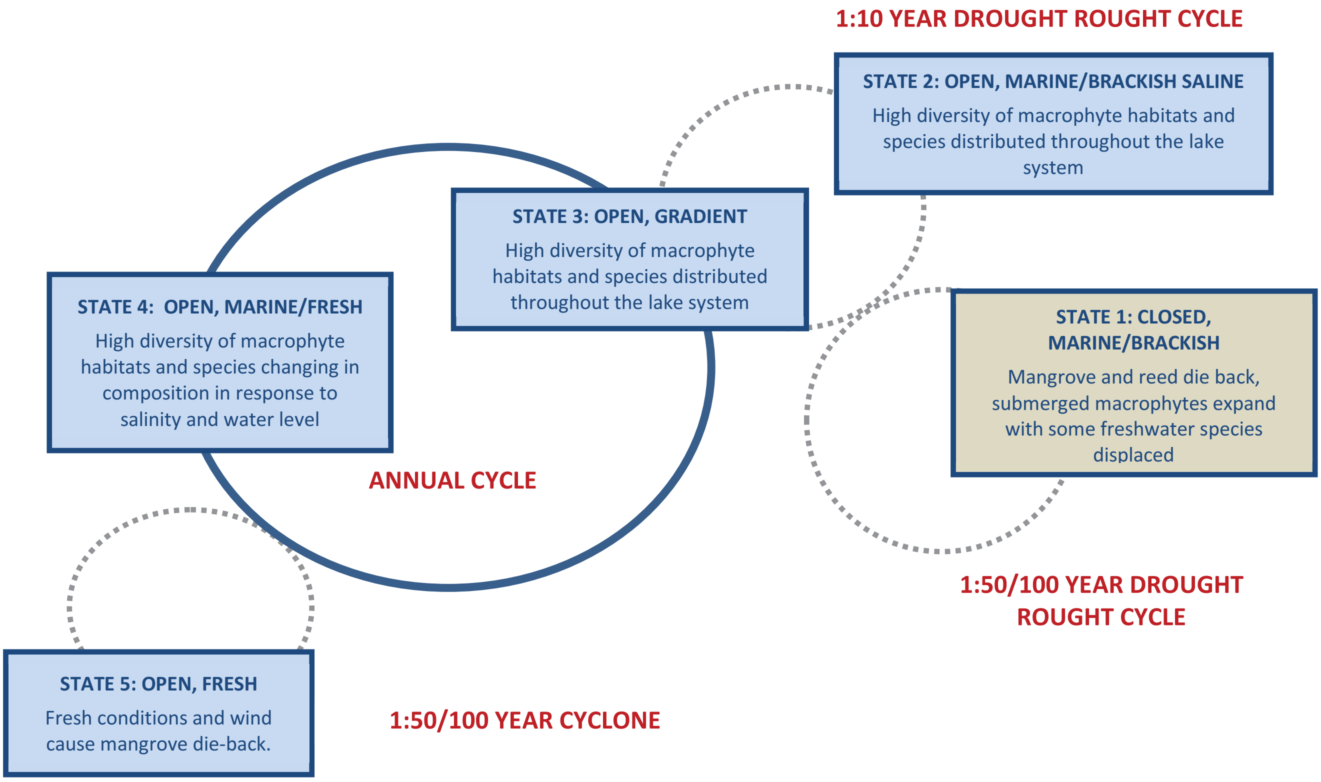


Figure H.6 Kosi: Macrophyte Conceptual model

The main changes in habitat will occur around water level and salinity (Tables H.17 and H.18). As inflow decreases and salinity will increase then habitat will adjust their hydroperiod and response for salinity will be at the species level. With mouth closure and increased inundation then mangroves and reeds will die back, as will salt marsh in the lower reaches. The overall water level change will be approximately 10 cm only over one-month maximum period (Dec/Jan), then response (gain/loss) will be minimal (1 to 6% change from present). Mangroves nor swamp forest are affected by this small timeframe of inundation.

Table H.17: Kosi: Summary of change in water level predictions and associated responses of mangroves in zones A, B and C and submerged macrophytes in Zone D

KOSI: PRESENT						SCENARIO 1					SCENARIO 2				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (17 YEAR SIMU															
Jan	0.60	1.12	1.12	1.12	-	0.60	1.12	1.12	1.12	1.12	0.60	1.17	1.17	1.17	1.12
Feb	0.60	1.18	1.18	1.18	-	0.60	1.02	1.02	1.02	1.02	0.60	1.18	1.18	1.18	1.02
Mar	0.60	0.96	0.96	0.96	-	0.60	0.85	0.85	0.85	0.85	0.60	0.95	0.95	0.95	0.85
Apr	0.60	0.86	0.86	0.86	-	0.60	0.69	0.69	0.69	0.69	0.60	0.81	0.81	0.81	0.69
May	0.60	0.57	0.57	0.57	-	0.60	0.56	0.56	0.56	0.56	0.60	0.57	0.57	0.57	0.56
Jun	0.60	0.70	0.70	0.70	-	0.60	0.70	0.70	0.70	0.70	0.60	0.70	0.70	0.70	0.70
Jul	0.60	0.75	0.75	0.75	-	0.60	0.75	0.75	0.75	0.75	0.60	0.70	0.70	0.70	0.75
Aug	0.60	0.57	0.57	0.57	-	0.60	0.68	0.68	0.68	0.68	0.60	0.68	0.68	0.68	0.68
Sep	0.60	0.69	0.69	0.69	-	0.60	0.69	0.69	0.69	0.69	0.60	0.69	0.69	0.69	0.69
Oct	0.60	0.67	0.67	0.67	-	0.60	1.01	1.01	1.01	1.01	0.60	0.89	0.89	0.89	1.01
Nov	0.60	1.07	1.07	1.07	-	0.60	0.96	0.96	0.96	0.96	0.60	0.96	0.96	0.96	0.96
Dec	0.60	0.97	0.97	0.97	-	0.60	0.87	0.87	0.87	0.87	0.60	0.97	0.97	0.97	0.87

	SCENARIO 3					SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
Jan	0.60	1.12	1.12	1.12	1.12	0.60	1.17	1.17	1.17	1.12
Feb	0.60	1.07	1.07	1.07	1.02	0.60	1.07	1.07	1.07	1.02
Mar	0.60	0.90	0.90	0.90	0.85	0.60	0.95	0.95	0.95	0.85
Apr	0.60	0.86	0.86	0.86	0.69	0.60	0.86	0.86	0.86	0.69
May	0.60	0.57	0.57	0.57	0.56	0.60	0.57	0.57	0.57	0.56
Jun	0.60	0.70	0.70	0.70	0.70	0.60	0.70	0.70	0.70	0.70
Jul	0.60	0.75	0.75	0.75	0.75	0.60	0.70	0.70	0.70	0.75
Aug	0.60	0.57	0.57	0.57	0.68	0.60	0.57	0.57	0.57	0.68
Sep	0.60	0.69	0.69	0.69	0.69	0.60	0.68	0.68	0.68	0.69
Oct	0.60	0.83	0.83	0.83	1.01	0.60	0.62	0.62	0.62	1.01
Nov	0.60	1.07	1.07	1.07	0.96	0.60	0.91	0.91	0.91	0.96
Dec	0.60	1.13	1.13	1.13	0.87	0.60	0.97	0.97	0.97	0.87

Table H.18: Kosi: Predicted salinity and associated responses in submerged macrophytes (green = favourable conditions, salinity < 15)

KOSI:	PRESENT					SCENARIO 1					SCENARIO 2					SCENARIO 3					SCENARIO 4				
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E	Zone A	Zone B	Zone C	Zone D	Zone E
SEASONAL DISTRIBUTION (17 YEAR SIMULATION PERIOD)																									
Jan	35	27.5	17.6	3.2	0.9	35	27.5	17.6	3.2	0.8	35	27.2	17.4	2.9	0.8	35	27.5	17.6	3.2	0.8	35	27.2	17.4	2.9	0.8
Feb	35	27	17.1	2.4	0.6	35	27.9	17.9	3.2	0.6	35	27	17.1	2.4	0.6	35	27.6	17.6	2.9	0.6	35	27.6	17.6	2.9	0.6
Mar	35	28.4	18.5	4.1	1.1	35	29.2	19.4	5.3	1.3	35	28.6	18.8	4.7	1.3	35	28.9	19.1	5	1.3	35	28.6	18.8	4.7	1.3
Apr	35	28.8	18.8	4.1	0.9	35	29.9	20	5.6	1	35	29.1	19.1	4.4	1	35	28.8	18.8	4.1	1	35	28.8	18.8	4.1	1
May	35	31.2	21.5	7.9	2.2	35	31.6	22.1	9.1	2.2	35	31.2	21.5	7.9	2.2	35	31.2	21.5	7.9	2.2	35	31.2	21.5	7.9	2.2
Jun	35	29.6	19.7	5	1.1	35	29.6	19.7	5	1.1	35	29.6	19.7	5	1.1	35	29.6	19.7	5	1.1	35	29.6	19.7	5	1.1
Jul	35	29.4	19.4	4.7	1.1	35	29.4	19.4	4.7	1.1	35	29.6	19.7	5	1.1	35	29.4	19.4	4.7	1.1	35	29.6	19.7	5	1.1
Aug	35	31.2	21.5	7.9	2.2	35	30.4	20.6	6.8	1.8	35	30.4	20.6	6.8	1.8	35	31.2	21.5	7.9	1.8	35	31.2	21.5	7.9	1.8
Sep	35	30.1	20.3	6.2	1.6	35	29.9	20	5.6	1.6	35	30.1	20.3	6.2	1.6	35	30.1	20.3	6.2	1.6	35	30.6	20.9	7.4	1.6
Oct	35	30.8	21.2	7.9	2.3	35	28.4	18.5	4.4	1.8	35	29.4	19.7	6.2	1.8	35	29.9	20.3	7.1	1.8	35	31.1	21.5	8.2	1.8
Nov	35	27.8	17.9	3.5	0.9	35	28.4	18.5	4.1	1.1	35	28.4	18.5	4.1	1.1	35	27.8	17.9	3.5	1.1	35	28.7	18.8	4.4	1.1
Dec	35	27.9	17.9	2.9	0.6	35	28.5	18.5	3.5	0.6	35	27.9	17.9	2.9	0.6	35	27.1	17.1	2.1	0.6	35	27.9	17.9	2.9	0.6

Responses of Macrophytes to different scenarios are illustrated in Table H.19 and H.20.

Table H.19: Kosi: Predicted change in macrophytes under Present State and Future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	Mangroves occur in Zones A, B and C (71 ha). Submerged macrophytes occur in Zones B to E, particularly in Zone D (652 ha). Species more tolerant of brackish conditions occur in Lake 3 (Zone D, Nhlange) such as *Stuckenia pectinata* and *Zostera capensis, Ruppia cirrhosa. Halodule uninervis* occur in Lake 1 (Zone A, lower estuary). Reeds and sedges occur throughout the system as well as along seepage areas near the mouth (127 ha). Saline grasses and salt marsh occur in low lying areas around Zones B and C (Lake 1 and 2) (287 ha). Swamp Forest occurs along seepage areas for example near the mouth (869 ha). Macroalgae occur around Zone D (Lake 3).
1	**Key driver: 6% decrease in freshwater inflow and > 1% increase in mouth closure.** Mangroves will decrease in Zones 1, 2 and 3 due to the increased duration of mouth closure that will inundate mangroves causing die-back, especially for periods longer than 5 months. Submerged macrophytes will increase and there will be a change in Zone B (Lake 1) to more saline tolerant species. Reeds and sedges will decrease because of the increase in salinity but will increase when the mouth is closed so overall small change in reeds and sedges. Saline grasses and salt marsh will decrease around the low-lying levels of Zones 2 and 3 (Lake 1 and 2) due to mouth closure and inundation. Swamp Forest will decrease as seepage areas decrease.
2	**Key driver: 1% increase in freshwater inflow and > 1% increase in mouth closure.** Mangroves will increase between Zones A, B and C (Lake 1 and 2) due to the increased duration of mouth opening. Submerged macrophytes will increase in Zone D. Reeds and sedges will increase as more habitats becomes flooded and available. Saline grasses and salt marsh in the low-lying areas around Zones 2 and 3 (Lake 1 and 2) will decrease due to inundation. Swamp Forest will increase as seepage areas increase.
3	**Key driver: 2% increase in freshwater inflow and > 1% increase in mouth closure.** Mangroves will increase between Zones 2 and 3 (Lake 1 and 2) although any increased duration of mouth closure will result in increased inundation of mangrove habitat causing their possible die back. Submerged macrophytes will decrease and there will be a change in Zone B (lake 1) to more salinity tolerant species. Reeds and sedges will decrease because of the increase in salinity. Saline grasses and salt marsh will increase around the low-lying levels of Zones 2 and 3 (Lake 1 and 2). Swamp Forest will increase.
4 Far future	**Key driver: 2% decrease in freshwater inflow and < 1% decrease in mouth closure.** Mangroves will decrease between Zones 1, 2 and 3 due to the increased duration of mouth closure that will result in increased inundation of mangrove habitat causing their possible die back, especially for longer periods. Submerged macrophytes will increase and there will be a change in Zone B (lake 1) to more salinity tolerant species. Reeds and sedges will decrease because of the increase in salinity but will increase due to the increased duration of mouth closure. Saline grasses and salt marsh will decrease around the low-lying levels of Zones 2 and 3 (Lake 1 and 2) due to mouth closure and inundation.

SCENARIO	SUMMARY OF CHANGES
	Swamp Forest will decrease as seepage areas decrease. In 100 years, the mouth will close twice this will result in loss of mangroves and seagrass as rate of recovery may take 20 years.

Table H.20: Kosi: Direction of change in macrophytes under Present State and Future Climate Change Scenarios

<table>
<tr><th>SCENARIO</th><th>ZONE A</th><th>ZONE B</th><th>ZONE C</th><th>ZONE D</th><th>ZONE E</th></tr>
<tr><td>Scenarios 1</td><td rowspan="4">↓ mangroves
↓ salt marsh</td><td rowspan="4">↓ mangroves
↓ salt marsh</td><td rowspan="4">↓ mangroves
↓ salt marsh</td><td rowspan="4">↑ submerged macrophytes</td><td rowspan="4">↓ swamp forest</td></tr>
<tr><td>Scenario 2</td></tr>
<tr><td>Scenario 3</td></tr>
<tr><td>Scenario 4</td></tr>
<tr><td>Scenario 5</td><td colspan="3">↓ mangroves ↓ salt marsh ↑reeds</td><td></td><td></td></tr>
<tr><td>Scenario 6</td><td colspan="3">↓ mangroves
↓ salt marsh</td><td colspan="2">↓ submerged
↓ swamp forest
↑ mangroves
↑ salt marsh</td></tr>
</table>

H.3.3 Fish

From a fish perspective, the Kosi estuarine system is unique in South Africa as a series of connected estuarine lakes with very clear subtropical waters and salinities ranging from fresh (0) to near seawater (35). Kosi is also the only estuarine system of significant size that flows into an area of coastal sea where coral reefs occur, a reflection of its location on the warm, Agulhas influenced coast of KwaZulu-Natal near the South Africa / Mozambique border. Kosi is the country's lowest latitude estuarine system, and this is reflected in the fish assemblage which is tropical in nature compared to systems to the south. In addition to its location within a protected UNESCO World Heritage Site, these factors contribute to the system supporting a particularly wide diversity fishes, including species not reported from any other South African estuaries. However, the presence of a small section of reef at the estuary mouth also plays a significant role in supporting species not reported from other South African estuaries. This reef is inhabited by an abundance of marine species which are primarily associated with reef habitats and have little or no dependence on estuaries. These include members of the Acanthuridae, Scaridae, Labridae, Chaetodontidae, Pomacentridae, Serranidae and Muraenidae. Most of the species in this group do not occur in any of the systems estuarine habitats (see Blaber 1978). However, several species, which are normally associated with reef and other marine habitats, also occur in what are typical estuarine habitats in the lower reaches of the Kosi estuary (where salinities are > 25). For example, Apogonidae, Scorpaenidae, and even Sargassumfish *Histrio histrio* (Antennariidae) have been sampled in *Zostera* and *Ruppia* seagrasses near the estuary mouth, as have Muraenidae and Blenniidae from mangrove areas (Weerts, unpublished). The occurrence of many of these marine species, although interesting, cannot be attributed to any estuarine function of the system.

There is, however, an abundance of marine fishes which occur in the Kosi system, and which are strongly associated with its estuarine nature. Many of these fishes occur in the lakes in higher abundances and at larger size classes than in other South African systems. This holds true for several estuarine dependent marine fishes (Whitfield's fish categories IIa and IIb) as well as estuarine opportunistic marine species (Whitfield's fish categories IIc and III). In the case of both these latter groups these fishes occur in the lakes as juveniles as well as adults, and rich prey abundances appear to be an influential factor in this. There appear to be some linkages between estuarine habitats, particularly clear water mangroves, and the offshore coral reefs. This is evidenced by the abundance and large sizes of several members of the Lutjanidae (snappers) in the Kosi lakes. This family of fishes includes many species that rely on linkages and demonstrate strong connectivity between mangroves and coral reef habitats in other parts of the world (e.g. Nagelkerken et al. 2000, 2002, Mumby et al. 2004, Mumby 2006).

There are also several obligate estuarine dependant species (estuarine residents; Whitfield's fish category I), which occur in the Kosi lakes in higher abundances and frequencies of occurrence than any other South Africa system. These are typically small-bodied species, which are important in the trophic dynamics of the system. They also include several members of the Gobiidae and Syngnathidae, which are otherwise rare in our estuaries. This is probably also true of several of the Eleotridae that have been reported from the system, although little is known about these species because of their cryptic habits.

Several freshwater species of fish also occur in Kosi. These include euryhaline freshwater forms with varying degrees of salinity tolerance and which typically also occur in estuaries elsewhere in South Africa. Examples are the Mozambique tilapia *Oreochromis mossambicus*, which occurs throughout the system (Blaber 1978) and Sharptooth catfish *Clarias gariepinus* which penetrates the Mtando Channel between Lakes 3 and 2 at least (pers. obs). More stenohaline freshwater species occur but are restricted to the freshwater in the upper reaches of the Kosi linked lake system, and in the inflowing streams. Although not typically included in estuarine fish assemblages, these fishes warrant inclusion in this assessment because of the nature of the system as a series of linked lakes ranging in salinity from fresh- to near seawater. Because of the flat topography of the region and small size of peripheral freshwater streams, these fishes are most threatened by reduced freshwater inputs, and are at greatest risk in the Kosi system during times of drought.

Obligate catadromous fishes in Kosi are represented solely by eels of the family Anguillidae. These eels occur as elvers, juveniles and adults in the lakes as well as their connected freshwaters, although spawning and egg and larval distribution occur in the adjacent marine environment. Kosi's catchments are not particularly large, but its associated freshwaters are probably significant for the shortfin eel, Anguilla bicolor, a species apparently restricted to coastal lowlands (Skelton 1993). Kosi is also the only (near) permanently open estuary, connecting the marine environment with estuarine and freshwaters along a very long stretch of coast from Mfolozi-St Lucia to Maputo, a distance of some 300 km. This renders the system important for all anguillid eels, as well as other estuarine associated marine spawning fishes.

From the above is it apparent that fishes of life history and trophic guilds typical of estuaries in South Africa (and elsewhere in the world) occur in the Kosi linked lakes system. Atypically, however, the fish assemblage includes a component of marine (coral) reef fishes (with apparent tolerance of reduced (poyhaline) salinities) and a component of freshwater fishes which although common of coastal freshwaters, seldom occur in estuaries.

Conceptual responses of different components of the fish assemblage to different states are presented in Figure H.7. Preliminary modelled fish abundance (relative) based on Whitfield's (2019) estuarine association categories are presented in Table H.21. These are based primarily on predicted salinity regimes under the different states, with some consideration of trophic networks. Fish community response to the various climate change scenarios under consideration here will be driven by direct and indirect species responses to abiotic changes. Predicted abiotic changes which can be expected to have the greatest influence on fishes in Kosi are salinity, temperature, mouth closure and depth (as a response to mouth closure and sea-level rise in the case of Scenario 6).

Salinity is a primary determinant of fish distribution into the lakes. Estuarine fishes are tolerant of a wide range of salinities, typically more so of low rather than high salinities. Even the reef-associated marine fishes that occur at the mouth of Kosi, and which are atypical of estuaries, tolerate moderately reduced salinities in Kosi on a tidal basis. Estuarine dependent marine fishes (categories IIa and IIb) can tolerate very low salinities, and even freshwater, but most have preferences for waters with some salinity. Therefore, while their ranges in Kosi can, and do extend to zones that are very low salinity and fresh (Lakes Nhlange and Amanzimnyana, Zone D and E) under typical states (States 3 and 4), they occur in greatest abundances in more saline reaches (Zone A, B and C, the estuary, and saline Lakes Makhawulani and Mpungwini). Saline intrusion into the upper lakes under States 1 and 2 will see an increased abundance of several estuarine dependent marine piscivores, notable kingfish (*Caranx* spp.) and barracudas (*Sphyraena* spp.). Indirect effects of salinity (through influence on prey abundance) are likely, and indeed are probably more important than direct effects (through influence on salinity preferences) in the case of estuarine dependent marine benthivores.

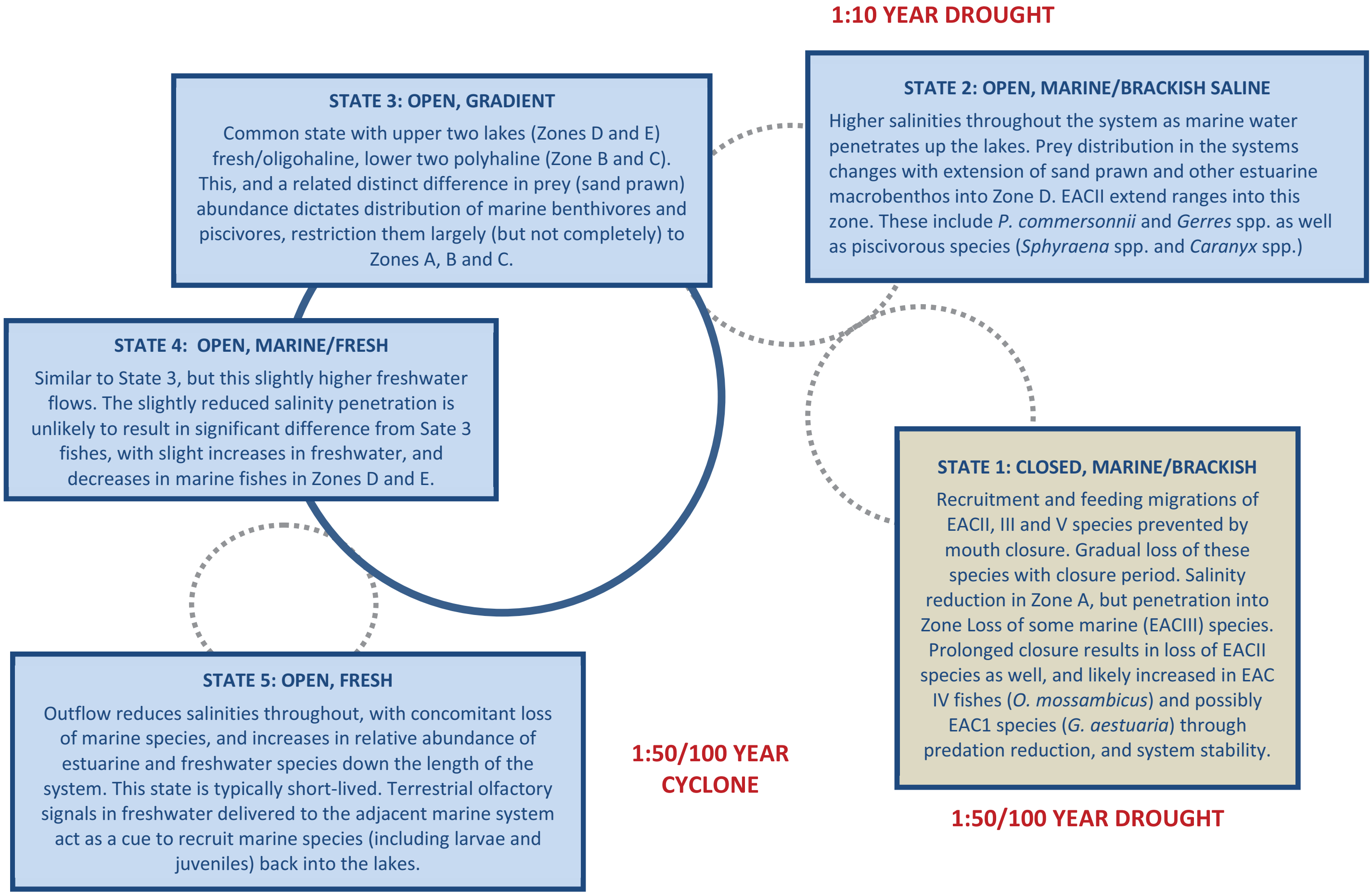


Figure H.7: Kosi: Fish Conceptual model

Table H.21: Kosi: Typical distribution of estuarine fish groups in various states (% abundance within each zone, p = likely present in low abundance < 0.5%)

STATE	CATEGORY	ZONE A: LOWER ESTUARY	ZONE B: MAKHAWULANI	ZONE C: MPUNGWINI	ZONE D: NHLANGE	ZONE E: AMANZIMNYANA
State 1: Closed, marine/brackish	I	63%	72%	71%	74%	80%
	IIa	17%	11%	10%	7%	9%
	IIb	9%	7%	8%	2%	0%
	IIc	2%	1%	1%	1%	0%
	III	2%	1%	p	0%	0%
	IV	7%	7%	10%	16%	10%
	V	0%	0%	0%	p	p
State 2: Open, marine/ brackish	I	28%	44%	42%	75%	81%
	IIa	27%	17%	13%	11%	10%
	IIb	18%	24%	33%	11%	1%
	IIc	13%	8%	7%	2%	1%
	III	13%	6%	3%	0%	0%
	IV	0%	1%	1%	1%	7%
	V	0%	0%	0%	p	p
State 3: Open, gradient	I	28%	51%	48%	81%	82%
	IIa	31%	19%	12%	9%	10%
	IIb	20%	20%	32%	4%	0%
	IIc	8%	4%	4%	1%	0%
	III	13%	3%	2%	0%	0%
	IV	0%	2%	1%	5%	8%
	V	0%	0%	0%	p	p
State 4: Open, marine/fresh	I	28%	60%	49%	83%	77%
	IIa	30%	16%	12%	7%	10%
	IIb	23%	18%	35%	1%	0%

STATE	CATEGORY	ZONE A: LOWER ESTUARY	ZONE B: MAKHAWULANI	ZONE C: MPUNGWINI	ZONE D: NHLANGE	ZONE E: AMANZIMNYANA
	IIc	8%	2%	2%	1%	0%
	III	10%	2%	0%	0%	0%
	IV	1%	2%	3%	8%	13%
	V	0%	0%	p	p	p
State 5: Open, fresh	I	37%	64%	59%	83%	75%
	IIa	32%	14%	11%	6%	9%
	IIb	16%	15%	24%	0%	0%
	IIc	6%	2%	2%	0%	0%
	III	8%	0%	0%	0%	0%
	IV	1%	4%	5%	10%	16%
	V	0%	0%	p	p	p

Estuarine macrobenthos, and particularly sandprawn *Kraussillichirus kraussi*, occurs much more abundantly in the saline Lakes Makhawulani and Mpungwini (Zones B and C) than the brack- and freshwater Lakes Nhlange and Amanzimnyana (Zones D and E). Saline intrusion into the upper lakes under States 1 and 2 see range extensions of these favoured prey items into Lake Nhlange especially, and consequently increased abundance of foraging estuarine dependent marine fishes in this lake. This is likely to be more marked in the lower reaches of Lake Nhlange, the nearest saline inflows from the Mtando channel.

Freshwater fishes are also affected by salinity intrusion into the system. Euryhaline freshwater forms occur throughout all the lakes under all states, but are typically more abundant in brack- and freshwater zones (Lakes Nhlange and Amanzimnyana, Zone D and E). Stenohaline forms are restricted to freshwater in the upper reaches (Lakes Amanzimnyana, Zone E) and inflowing streams. Under states of increased salinity distributional ranges of these species contract to freshwater refugia (inflowing steams and seeps). Conversely, under high flow states (State 5 in particular) these species can disperse across the wider system. These high flow states probably allow recruitment and genetic mixing in small Kosi freshwater catchments.

Under scenarios that result in long-term state changes salinity is likely to have greater impacts on fishes. Prolonged conditions of high salinity allow the establishment of larger populations of estuarine macrobenthos across the wider system, and consequently favour estuarine dependent marine benthivores such as spotted grunter (*Pomadasys commersonnii*) and pursemouths (*Gerres* spp.) However, indirect impacts to water quality (reduced oxygen) might occur through salinity-induced die-off of vegetation. These are difficult to predict and quantify.

Significant changes in air temperature are predicted under climate change scenarios considered here, particularly under Scenario RCP 8.5 Far-future where average monthly temperatures are forecast to increase by over 5°C. Actual water temperature will also increase, but not necessarily to the same degree. Empirical and deterministic modelling of the relationship between atmospheric and water temperature from elsewhere mostly covers ranges that are extreme for application here (at the low range) and points (expectedly), to lag and depth effects in water temperature response air temperature. This complication is exacerbated in the current work by a paucity of information on expected daily variation in temperature under the extreme climate change scenario considered. Nevertheless, temperature impacts to fish communities in Kosi Bay can be expected under Scenario RCP 8.5 Far. Different fish species can be expected to have different thermal limits and tolerance to temperature changes (Jeffries et al., 2016; Spies et al., 2016) and both life cycle and behavioural adaptations are likely responses to deal with elevated water temperature. Bottom water has been found to provide effective thermal refugia in systems where surface waters elevate to above threshold levels for fishes (Waltham and Sheaves, 2017), and moving to deeper waters to avoid predicted temperature extremes is likely to be a viable response for fishes in Kosi. However, early life stages with low mobility are likely to be vulnerable. Estuarine dependent species can be expected to be impacted most. These fishes have early life stages (eggs and larvae) restricted to the lakes where changes in temperate will be far more extreme than in marine waters. While adults, juveniles, and larvae to some extent can move to deep waters in response to high surface water temperatures, eggs in the upper water layers will remain vulnerable. Importantly several estuarine breeding species (e.g. the gobies *Glossobius giuris* and *Croilia mossambica* and Cape silverside *Atherina breviceps*) have adhesive eggs, which are laid on submerged vegetation. Submerged vegetation is largely restricted to shallow areas in Kosi and these eggs will clearly be subject to temperature extremes which could have significant impacts on their populations in Kosi.

Mouth closure will have several impacts on fish communities in Kosi, some of which will act synergistically. The clearest is a break in connectivity with the marine environment, precluding recruitment and immigration of marine species into the estuary and lakes, as well as emigration of species back to sea. Community impacts will increase in severity with duration of mouth closure but predicted closure periods are most short (weeks-months). Under Scenario 4 there is a low probability of month closure for up to two years, and this would have a marked effect of cohort classes in the estuary and lakes. Mouth closure will also cause changes in depth throughout the system because of gradual filling of the system in response to an elevated beach berm. These changes are likely to be slight and coincide with increases in salinity in the upper reaches of the system (with salinity impacts discussed above) but also some reduction in salinity in the lower reaches. These lower reach salinity reductions are not expected to impact estuarine associated species but may result in loss of the unique assemblage of marine reef species that occurs at the estuary mouth. These species will be replaced and recover quickly on mouth breaching and resumption of normal salinity regimes. Long term changes in depth may result in die of vegetation, reed banks in the upper reaches, and mangroves in the lower reaches. The former may have water quality implications (reduced oxygen on decay of organic matter) and both may reduce structural habitat available for fishes. This will be mitigated to some extent in the case of mangroves as dead trees will provide habitat for years, and in the case of reeds which will decay quicker, but soon establish in newly flooded areas.

A summary of predicted fish responses to different climate change scenario considered here is presented in Table H.22. Scenarios (1-4) considered here modelled salinity responses based on freshwater flows only and these show little change from present day distributions. Presumably, drought and rain cycles will elicit similar responses in the fish community as presently conceptualised in the system (Figure 10.6), but the distribution of these states under different climate change scenarios varies very little and differs very slightly from the present-day scenario (Figure 10.4). These changes are driven by abiotic changes (water quality), and biotic changes (vegetation), and confidence attached to the prediction here should probably be regarded as Low.

Table H.22: Kosi: Predicted change in fish under Present State and future Climate Change Scenarios

SCENARIO	SUMMARY OF CHANGES
Present	A unique (but atypical) community of reef-associated marine fishes occur in structure habitats (mangroves, seagrasses, and rubble) in the lower reaches (estuary, Zone A). This is a small component of this zones fish assemblage, which is dominated numerically by estuarine species and by biomass by estuarine dependant marine species. Key large species (*Pomadasys commersonni* and *Gerres* spp.) use the lower reaches mainly as a migration route to and from the lower two estuarine lakes (Zones B and C), which are their primary feed grounds. These two lakes are dominated numerically by estuarine residents and by biomass by estuarine dependant marine species. The upper two lakes (Zone D and E) are dominated by estuarine residents to an even greater degree, and freshwater species become increasingly abundant. In the lakes reed beds provide important habitat for some estuarine resident species (particularly *Ambassis* spp. as a predation refuge in the clear water. In the lower lakes this is augmented by mangrove rootstocks which are used by estuarine resident and estuarine dependant marine species. Sand prawns are important prey items in the lower lakes, while benthic microalgae, occurring at greater depths than in turbid estuaries, support mullet species.
1	Predicted salinity changes are minor and water quality changes are not expected to have a marked impact on fish communities. Increased mouth closure occurs, but generally for short periods. Some mangroves die-back may occur, but this will be offset by increases in submerged macrophytes in the lower reaches and dead trees persisting to provide some structure habitat. Small changes are predicted in reeds habitat.
2	Predicted salinity changes are minor and water quality changes are not expected to have a marked impact on fish communities. Increased mouth closure occurs, but generally for short periods. Some mangroves die-back may occur, but this will be offset by increases in submerged macrophytes in the lower reaches and dead trees persisting to provide some structure habitat. Small changes are predicted in reeds habitat.

SCENARIO	SUMMARY OF CHANGES
3	Predicted salinity changes are minor and water quality changes are not expected to have a marked impact on fish communities. Increased mouth closure occurs, but generally for short periods. Mangroves predicted to increase, but possible occasional die-off may occur, but this will be offset by dead trees persisting to provide some structure habitat. Small changes are predicted in reeds habitat.
4	Predicted salinity changes are minor and water quality changes are not expected to have a marked impact on fish communities. Longer periods of mouth closure may result in larger and more severe mangrove drowning, as well as die-off of reed banks. In the lower reaches mangrove habitat loss is offset by increases in submerged aquatic macrophytes. Reeds will recover quicker than mangroves, but some short-term water quality impacts are possible (lowered oxygen). Longer mouth closure (up to two years) will affect cohort class distributions in the system, and under prolonged mouth closure elements of the reef-associated marine assemblage at the mouth may be lost. Recruitment will be rapid on mouth breaching. Increased water temperature might have significant impacts on fish eggs and larvae of estuarine resident species, which numerically dominate the system.

I. OVERALL ESTUARINE HEALTH INDEX SCORING

Tables I.1 and I.2 present a summary of changes in abiotic and biotic conditions under the various scenarios in each of the lake systems. Health score ratings indicate the relative sensitivity of key indicator components the predicted change in each of the four climate change scenarios in comparison to present condition change.

Table I.1: Sensitivity of abiotic components for estuarine lakes under different Climate Change scenarios (as reflected in changes in EHI scores compared with the present)

SYSTEM	PRESENT	RCP 4.5 Mid	RCP 4.5 Far	RCP 8.5 Mid	RCP 8.5 Far
Hydrology					
Verlorenvlei	76	70	68	67	63
Bot/Kleinmond	81	73	72	67	63
Klein	77	77	78	71	65
Heuningnes	84	85	85	89	74
Touw/Wilderness	70	92	81	75	66
Swartvlei	68	69	66	66	70
uMgobezeleni	90	85	98	85	97
Kosi	92	84	94	94	89
Hydrodynamics (mouth state)					
Verlorenvlei	90	82	79	78	78
Bot/Kleinmond	79	61	59	55	61
Klein	72	68	73	63	44
Heuningnes	80	78	78	78	75
Touw/Wilderness*	60	68	63	56	49
Swartvlei	82	82	75	93	82
uMgobezeleni**	90	90	95	95	85
Kosi	99	99	99	99	95
Hydrodynamics (water level)					
Verlorenvlei	89	89	89	89	85
Bot/Kleinmond	88	91	91	92	89
Klein	93	93	94	94	96
Heuningnes	88	85	85	86	82
Touw/Wilderness	85	86	85	86	84
Swartvlei	84	83	84	82	85
uMgobezeleni	95	95	95	95	94
Kosi	99	99	99	99	90
Salinity					
Verlorenvlei	96	96	96	96	96
Bot/Kleinmond	88	94	93	94	93
Klein	92	89	92	91	89
Heuningnes	41	38	37	39	37
Touw/Wilderness	80	79	79	80	81
Swartvlei	72	72	72	72	75
uMgobezeleni	98	98	98	98	97
Kosi	99	99	100	99	95
General Water Quality					
Verlorenvlei	28	28	28	28	28
Bot/Kleinmond	50	45	45	45	47
Klein	43	43	43	43	41
Heuningnes	72	72	72	72	72
Touw/Wilderness	82	82	82	82	82
Swartvlei	80	80	80	80	80
uMgobezeleni	73	73	73	73	73
Kosi	90	90	90	90	90

**Adjustments to score reflect changes in mouth configuration and siltation of lower reaches*
***Scores adjusted for artificial breaching*

Table I.2: Sensitivity of biotic components for estuarine lakes under different Climate Change scenarios (as reflected in changes in EHI scores compared with present)

SYSTEM	PRESENT	RCP 4.5 Mid	RCP 4.5 Far	RCP 8.5 Mid	RCP 8.5 Far
Microalgae (phytoplankton)					
Verlorenvlei	56	56	56	56	43
Bot/Kleinmond	80	78	78	78	78
Klein	68	68	70	68	60
Heuningnes	84	84	84	84	78
Touw/Wilderness	90	90	90	90	79
Swartvlei	75	75	76	73	70
uMgobezeleni	79	79	79	79	67
Kosi	89	89	89	89	86
Microalgae (benthic)					
Verlorenvlei	72	72	72	72	62
Bot/Kleinmond	90	91	91	91	89
Klein	78	78	78	78	76
Heuningnes	76	76	76	76	73
Touw/Wilderness	60	61	60	60	58
Swartvlei	88	86	88	86	79
uMgobezeleni	95	95	95	95	95
Kosi	88	88	88	88	79
Microalgae (harmful algal blooms)					
Verlorenvlei	62	62	62	62	60
Bot/Kleinmond	88	86	86	84	84
Klein	73	73	73	73	72
Heuningnes	95	95	95	95	89
Touw/Wilderness	91	93	91	91	89
Swartvlei	86	86	88	84	73
uMgobezeleni	67	67	67	67	61
Kosi	89	89	89	89	84
Macrophytes					
Verlorenvlei	50	48	48	48	45
Bot/Kleinmond	87	85	85	85	80
Klein	70	70	68	65	60
Heuningnes	60	58	58	58	56
Touw/Wilderness	78	78	78	78	75
Swartvlei	75	75	70	77	73
uMgobezeleni	70	70	70	70	65
Kosi	90	90	90	90	70
Fish					
Verlorenvlei	40	37	37	37	35
Bot/Kleinmond	75	75	75	75	70
Klein	70	65	70	60	45
Heuningnes	60	60	60	60	50
Touw/Wilderness	64	70	65	60	50
Swartvlei	75	75	70	80	75
uMgobezeleni	86	86	86	86	65
Kosi	89	89	89	85	80